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"Evaluating the Compressive Strength and Workability Performance of Concrete: Using Demolished Concrete Waste as Fine Aggregate Replacement"

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K E Y W O R D S

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A B S T R A C T

Accompanying the increase in awareness of sustainable methods of construction, the need for innovative material efficiency solutions has also arisen. This paper reports a study on the use of RFA manufactured from C&D waste as partial and full replacement of natural fine aggregates in concrete. Concrete with 0%, 50%, and 100% RFA replacement were prepared for investigating their compressive strength and workability. Workability decreased with increased RFA content, with slump values ranging from 14 to 8 to 5 mm for 0%, 50%, and 100% RFA contents, respectively. The control mix achieved a strength of 16.57 MPa at 28 days, while the 50% RFA mix had the highest value of 23.67 MPa-approximately 7 MPa more than that of the control mix. The corresponding strength recorded by the 100% RFA mix was 17.91 MPa, indicating its mediocre performance associated with reduced workability. These results confirm that the replacement level of RFA, which provides the best compromise between strength and workability, is 50%. Hence, it is suitable for non-structural and semi-structural applications. More importantly, the consumption of RFA in concrete manufacturing reduces the demand on natural resource utilization and generates less waste, hence fulfilling some of the key sustainable development criteria within the construction industry.

1. Introduction

After water, concrete is the most consumed material in the world and is considered the backbone of modern infrastructure. The rapid rate of urbanization and increase in population have resulted in an alarming depletion of natural aggregates and exponential rises in construction and demolition wastes. Construction and demolition wastes globally are estimated to comprise 30-40% of total solid wastes, and several countries generate hundreds of millions of tons of wastes annually. In Pakistan, like many developing countries, such wastes are disposed of inefficiently, causing land scarcity, environmental degradation, and unsustainable extractions of natural river sand and other aggregates. Both issues have made the implementation of sustainable construction practices-most notably, the recycling of C&D waste into RFA as a substitute for natural aggregates-imperative. These measures not only help reduce the environmental footprint of the construction industry but also support the development of a circular economy.

Although RFA is expected to be a sustainable alternative, its use in concrete is not exempt from problems. Higher water absorption, induced by the porous nature of RFA, negatively impacts the properties of fresh concretes, especially workability, and can potentially degrade the mechanical performance of hardened concrete. Many investigators have worked on the use of various types of recycled aggregates, but variability in experimental design, curing conditions, and replacement levels has made it difficult to find consistent and comparable trends in the test results. No effort has been systematically made in studying the impact of RFA replacement on both fresh and hardened concrete properties under identical conditions. This calls for further experimentation to establish more clear-cut evidence of RFA's suitability for conventional concrete mixes.

2. Literature Review

The growing volume of construction and demolition (C&D) waste has made its recycling a crucial element in promoting sustainability within the construction industry. Researchers have shown that incorporating recycled aggregates helps minimize the pressure on landfills and preserves natural resources, all while maintaining acceptable structural performance. For example, Kumar and Kumar (2023) found that the application of recycled aggregates with mineral admixtures can enhance both durability and mechanical strength compared with mixes made from natural aggregates. Similarly, Yehia et al. (2015) identified that even concrete prepared with 100% recycled aggregates can offer acceptable strength and durability, provided the mixture attains a proper packing density.

Using RFA in concrete isn't without its drawbacks. One of the main issues is their higher porosity and greater water absorption, which tend to affect both workability and durability. According to Nanya et al. (2021), using recycle fine aggregate up to about 50% can still meet basic structural requirements. Once the replacement goes beyond that point, the mix becomes noticeably less dense and takes in more water. Berredjem et al. (2020) also pointed out that when natural sand is completely replaced, the concrete shows higher porosity and becomes more vulnerable in harsh environmental conditions. In fact, Jagannadha Rao and Sastri (2016) observed that concrete with recycled aggregates doesn't perform as well as natural aggregate concrete when it comes to acid resistance.

Different methods of pretreatment have received considerable attention in the recent past, mainly to enhance the quality of the RFA. For example, Jean et al. (2024) found that using a carbonation treatment made a clear difference. It increased the density of the material, lowered its water absorption, and even boosted the compressive strength by almost 20% compared to untreated RFA. Cuenca et al. (2021) showed that the recycled ultra-high-performance concrete made using RFA had equivalent durability to the virgin aggregate when supplementary cementitious materials were utilized. Chandar et al. (2018) also suggested that combining the RA with other alternative materials like coconut shells could make durable mixes for non-structural uses.

Various studies confirm the existence of optimum replacement levels. Sai (2018) determined that up to 40% substitution of natural aggregates with recycled aggregates provided acceptable strength and durability, though strength reduction set in at higher levels. Yadav & Pathak (2018) assessed that durability like that of natural aggregates was achieved by processed recycled aggregates with adhered mortar removed. Abadel, in 2023, investigated ultra-high performance geopolymer concrete with recycled fine aggregates and showed that up to 20%, there is no loss of strength, although slight reductions at higher replacement percentages are observed due to weak interfacial bonding.

While significant achievements have been achieved, still certain gaps exist in long-term durability under aggressive conditions. For instance, Gayathri et al. (2025) have demonstrated that the ternary blending of recycled aggregate and fiber can substantially improve resistance against chloride penetration and drying shrinkage, indicating hybrid methods to transcend limitations. Ashwathi et al. (2025) have presented machine learning models for the prediction of recycled aggregate concrete strength, emphasizing AI-driven optimization in mix design.

3. Methodology

3.1 Material and Mix Design

Ordinary Portland Cement conforming to ASTM C150 was used. Crushed stone was used as coarse aggregate, and RFA was obtained from processed waste from construction and demolition activities. The concrete mixes were prepared based on the 1:2:4 proportion. Concrete mixes were prepared based on a 1:2:4 proportion. RFA was added at replacement percentages of 0, 50, and 100%. All mixes had a constant water-cement ratio of 0.6. There is an understanding that the use of a constant water-cement ratio might not result in the optimization of workability or strength performance for each mix, especially at high contents of RFA due to increased water absorption. However, the intention of this study was to provide a consistent baseline for comparison rather than to optimize each mixture individually. The Table 1 below outlines the specific quantities for each component:

Table 1: Mix Composition and Proportions of different batches

Sr. No.	Replacement %	Cement (kg)	Fine Aggregate (kg)	Replaced Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (kg)
1	0%	8	16	0	32	4.8
2	50%	8	8	8	32	4.8
3	100%	8	0	16	32	4.8

3.2 Experimental Procedures

Material preparation was the first step in the experimental work. Demolition waste concrete was collected, which was crushed into smaller pieces, and oversized particles were removed by sieving; finally, it was washed to eliminate dust, dirt, and all impurities for proper cleaning to produce clean RFA to be used in mixing. The prepared mixture was mixed using a rotary mixer. In the designed proportions, the cement, natural aggregates, and recycled fine aggregates were added with water and mixed until homogeneous and consistent mass was achieved to ensure the homogeneous distribution of the recycled material in the concrete matrix.

The slump test was conducted immediately after fresh concrete preparation, as outlined in ASTM C143, which stipulates the flowability and ease of handling of concrete. The standard cube specimens of 150 mm were prepared & compacted properly. For each batch, three cubes were prepared and tested in order to obtain reliable average values. These specimens were then submerged in water at room temperature for curing periods of 3 days and 28 days. Subsequently, the cubes were tested for compressive strength on a Universal Testing Machine according to codes ASTM C39. In this way, the effects of RFA replacement on concrete's mechanical properties could be studied systematically.

4. Results and Discussion

4.1 Workability Analysis

The workability of the concrete mixes decreased as the amount of recycled fine aggregate (RFA) increased, as shown by the slump test results in Table 2. The control mix, which contained no RFA, had the highest slump value at 14 mm, indicating better flow and ease of placement. In comparison, the mixes with 50% and 100% RFA showed noticeably lower slump values of 8 mm and 5 mm, respectively. This drop in slump can be mainly linked to the higher water absorption of the recycled aggregates, which reduces the amount of free water available to aid workability.

Based on ASTM C143, slump values in the range of 5–14 mm fall under the "very low" to "low" workability category. Concretes of this type are generally used in applications where high flowability isn't essential such as mass concrete works, footings, or rigid pavement bases where mechanical vibration assists in proper placement. When better flow and ease of placement are needed, the concrete mix can be fine-tuned—either by using chemical admixtures or tweaking the water–cement ratio. While adding more RFA does make the mix stiffer, it can still be a practical choice for many construction uses where extremely high workability isn't necessary.

4.2 Compressive Strength of Concrete

The compressive strength results clearly demonstrated that the influence of recycled fine aggregate (RFA) replacement on the performance of the concrete mixes. For 0% RFA, the average compressive strength was 6.69 MPa after 3 days of curing and 16.57 MPa after 28 days, as shown in Table 3. These values stand for the standard mechanical properties of conventional concrete. As shown in Table 4, the compressive strength significantly increased to 9.56 MPa after 3 days and 23.67 MPa after 28 days when 50% of the natural fine aggregates were substituted with RFA. This improvement indicates that partial substitution achieved a well-balanced mix between natural and recycled aggregates, resulting in enhanced internal bonding and more efficient strength development.

Table 2: Workability Analysis

Sr. No	%age of Recycled Fine Aggregate	W/C Ratio	Slump (mm)
1	0%	0.6	14
2	50%	0.6	8
3	100%	0.6	5

The mix including 100% recycled fine aggregate (RFA), on the other hand, achieved average compressive strengths of 6.92 MPa after 3 days and 17.91 MPa after 28 days, as indicated in Table 5. These results are marginally better as compared to the control mix. As illustrated in Figure 1, the fully recycled concrete still trailed behind the 50% replacement mix, particularly in terms of strength gain over time.

Overall, the mix having 50% recycled fine aggregate (RFA) showed noticeably better mechanical behavior in comparison to both standard and fully recycled concretes. It achieved higher compressive strength and performed consistently well, making it suitable for semi-structural elements where only moderate load-bearing capacity is needed. On the other hand, the mix made entirely with RFA, though still usable, tended to be less workable and may face durability issues over time because of its lower slump and greater porosity. Taking these factors together, the 50% replacement level seems to strike the most reasonable balance offering solid strength, manageable workability, and meaningful environmental benefits.

Table 3: Compressive Strength of 0% Replacement		
Compressive Strength of 0% Replacement		
Sr. No	**3 Days Compressive Strength (MPa)**	**28 Days Compressive Strength (MPa)**
01	6.15	15.90
02	7.01	16.70
03	6.91	17.12
Average	**6.69**	**16.57**

Table 4: Compressive Strength of 50% Replacement		
Compressive Strength of 50% Replacement		
Sr. No	**3 Days Compressive Strength (MPa)**	**28 Days Compressive Strength (MPa)**
01	9.13	22.60
02	10.03	24.84
03	9.51	23.56
Average	**9.56**	**23.67**

Table 5: Compressive Strength of 100% Replacement		
Compressive Strength of 100% Replacement		
Sr. No	**3 Days Compressive Strength (MPa)**	**28 Days Compressive Strength (MPa)**
01	7.67	17.76
02	7.27	15.97
03	5.84	20.02
Average	**6.93**	**17.91**

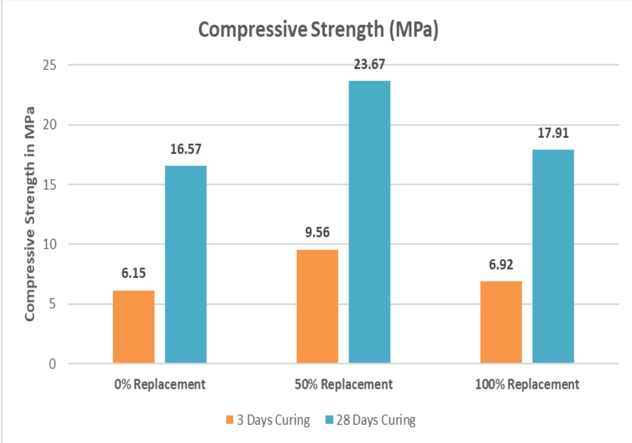

Figure 1: Comparison of 3-day and 28-day compressive strength results for concrete containing 0%, 50%, and 100% Recycled fine aggregate (RFA)

4.3 Practical Implications:

The results of this study indicate that recycled fine aggregates (RFA) can be effectively used in variety of construction work, aligning well with sustainable building techniques. While the control mix showed consistent performance, the mix containing 50% RFA achieved the best overall balance between workability and strength. This makes it a sensible option for semi-structural applications such as elements of low-rise buildings, lightly loaded slabs, or partition walls. On the other hand, the mix with 100% RFA also performed reasonably well but exhibited a noticeable decrease in workability and a slight reduction in strength compared to the 50% mix. Because of this, it seems more suitable for non-structural elements like pedestrian paths, curbstones, and other secondary works. Beyond the technical aspects, using RFA helps reduce the amount of construction and demolition waste sent to landfills and lowers the demand for natural aggregates. Overall, incorporating RFA into concrete manufacturing supports environmental sustainability and can help reduce costs by lowering the need for new raw materials.

5. Conclusion

Results obtained from the study indicate that RFA can serve as a good substitute for natural aggregates in concrete. This is clearly justified from the data obtained. For example, a control mix with 0% RFA attained an average compressive strength of 16.57 MPa at 28 days of age. This is in comparison with the mix with 50% RFA attaining as high a value as 23.67 MPa at the same age-about 7 MPa higher than what was obtained for the conventional mix. Even the 100% RFA mix performed reasonably well, achieving 17.91 MPa, but it was somewhat less effective than the 50% replacement. Overall, the results show that the use of

50% RFA yields the optimum balance of the advantages of strength, workability, and sustainability benefits. This improvement is apparently obtained because of the complementary roles played by natural sand and RFA: while natural sand maintains the density and lowers porosity, RFA adds to surface roughness and helps in internal curing, leading to better packing, bonding, and hydration.

Moreover, the study has few limitations. The water–cement ratio was maintained constant at 0.6 for all mixes, which may not be the optimal value for each replacement level. No chemical admixtures or supplementary cementitious materials were used, either, although these could further enhance workability and strength. Moreover, the curing was done for only 3 and 28 days without any long-term tests for durability. This points out that any future research should look into these shortcomings by focusing on the study of the effects of using admixtures, different curing periods, and durability in various environmental conditions. This would give a complete picture of the uses of RFA in structural and semi-structural applications.

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Not available

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