

Evaluating the Effects of Recycled Aggregate Treatment Methods on the Mechanical Properties of Concrete

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ABSTRACT: The increasing generation of construction and demolition waste and the depletion of natural aggregate resources have increased the need for sustainable alternatives in concrete production. Recycled concrete aggregate (RCA) offers a viable solution; however, its high porosity, water absorption, and adhered mortar may adversely affect concrete performance. This study evaluated the effects of recycled aggregate treatment methods on the mechanical and durability properties of concrete. Three recycled aggregate conditions were investigated: non-treated recycled aggregate (NTRA), water pre-soaked recycled aggregate (PTRA), and cement slurry-treated recycled aggregate (STRA). Concrete specimens were produced at a constant water–cement ratio of 0.50 and evaluated using slump, compressive strength, water absorption, and chemical resistance tests. Compressive strength was determined at 7, 14, and 28 days. At 28 days, NTRA,

PTRA, and STRA recorded compressive strengths of 24.8, 26.1, and 29.3 MPa, respectively, with STRA achieving an 18.1% improvement over NTRA. PTRA recorded the highest slump of 60 mm, while STRA and NTRA achieved 55 and 45 mm, respectively. Water absorption decreased from 6.2% for NTRA to 5.6% for PTRA and 4.8% for STRA. Following chemical exposure, STRA recorded the highest residual compressive strength of 25.0 MPa compared with 22.5 MPa and 21.3 MPa for PTRA and NTRA, respectively. The study concludes that cement slurry treatment provides the most effective overall improvement in recycled aggregate concrete by enhancing strength and durability and reducing water absorption. Its adoption is recommended for sustainable concrete production where improved structural performance is required.

Keywords: *Recycled aggregate concrete; cement slurry treatment; compressive strength; water absorption; durability.*

1.0 Introduction

1.1 Research Problem

The conversion of waste concrete into recycled concrete aggregate (RCA) therefore represents a potentially sustainable strategy for reducing natural aggregate consumption, diverting construction waste from disposal facilities, and promoting circular material use within the construction industry (Ouyang et al., 2023; Peiris et al., 2025).

Consequently, RCA commonly exhibits higher porosity, greater water absorption, lower density, and reduced mechanical resistance compared with conventional natural aggregate (Alqarni et al., 2022; Ouyang et al., 2023; Peiris et al., 2025). These characteristics directly influence the fresh, mechanical, and durability performance of RAC.

Lu et al. (2023) established that the moisture condition of recycled aggregates significantly affects concrete workability, compressive strength, and durability. The rough texture, irregular particle shape, and high absorption capacity of RCA may increase water demand and accelerate slump loss. Untreated RCA may therefore cause a reduction in compressive strength, although the magnitude of this reduction depends on the quality of the parent concrete, aggregate replacement level, adhered mortar content, particle size, water–cement ratio, and concrete mixture proportions (Alqarni et al., 2022; Ouyang et al., 2023).

Liang et al. (2021) identified the transport of aggressive substances and associated reinforcement corrosion as significant durability concerns in recycled aggregate concrete. Increased moisture penetration may also accelerate deterioration under chemical exposure and repeated environmental actions. Several treatment techniques have been investigated to overcome the deficiencies of recycled aggregates. Reported treatment methods include mechanical abrasion, thermal treatment, acid treatment, accelerated carbonation, polymer impregnation, pozzolanic slurry immersion, nano-material modification, bio-deposition, water pre-soaking, and cementitious surface coating (Abdo et al., 2024; Ouyang et al., 2023; Peiris et al., 2025).

Odero et al. (2022) reported improvements in mechanical strength and water transport characteristics following cement slurry treatment of recycled aggregates. The observed improvements were attributed to pore filling, additional calcium silicate hydrate formation, and strengthening of the interfacial transition zone. Similarly, Alqarni et al. (2022) reported improvements in compressive strength, water absorption, and slump following different RCA treatment procedures.

Despite the increasing volume of research on recycled aggregate treatment, the comparative effectiveness of simple and practically accessible treatment methods remains insufficiently established. Previous studies have investigated cement slurry, sodium silicate immersion, mechanical abrasion, carbonation, polymer impregnation, nano-material treatment, and other modification processes (Alqarni et al., 2022; Ouyang et al., 2023; Peiris et al., 2025). However, relatively limited experimental evidence directly compares untreated RCA, water-pre-soaked RCA, and cement-slurry-treated RCA under an identical concrete mix design and controlled laboratory conditions.

An important research gap also exists in the integrated assessment of the fresh, mechanical, and durability properties of concrete produced with differently treated recycled aggregates. Many previous investigations have concentrated primarily on compressive strength or individual durability parameters. Such assessments may not provide a complete representation of RAC performance because improvements in one property may be accompanied by undesirable changes in another. For example, a treatment technique may improve compressive strength but provide limited reduction in water absorption, while

another treatment may improve workability without producing equivalent improvements in long-term durability.

Furthermore, variations in RCA source, parent concrete quality, treatment concentration, treatment duration, replacement ratio, concrete mixture proportions, curing conditions, and testing procedures complicate direct comparisons among published findings (Ouyang et al., 2023). Peiris et al. (2025) emphasised the continuing need for systematic assessment of RCA treatment techniques and integrated evaluation of durability-related performance. The research problem addressed in this study is therefore the inadequate comparative understanding of the influence of untreated, water-pre-soaked, and cement-slurry-treated recycled aggregates on concrete workability, compressive strength, and durability. It remains unclear which of these simple treatment conditions provides the most balanced improvement in RAC performance when the aggregates are incorporated into concrete produced using an identical mixture design.

1.2 Scope of the Study

This study is limited to the comparative experimental evaluation of concrete produced using three recycled aggregate conditions: untreated recycled aggregates, recycled aggregates pre-soaked in water, and recycled aggregates treated with cement slurry. The principal experimental variable is the treatment condition of the recycled aggregate. The investigation evaluates the influence of these treatment conditions on the fresh, mechanical, and durability performance of recycled aggregate concrete.

The study focuses on water pre-soaking and cement slurry treatment because these methods are comparatively simple and potentially adaptable to conventional concrete production.

1.3 Aim and Objectives of the Study

The aim of this study is to evaluate the effects of recycled aggregate treatment methods on the Mechanical Properties of concrete

The Specific Objectives are:

- i. To compare the compressive strength of concrete produced at 7, 14, and 28 days

- ii. To evaluate the durability of recycled aggregate concrete
- iii. To identify the most suitable concrete treatment method

With the increasing focus on sustainable construction practices, the use of recycled aggregates has gained significant attention as an eco-friendly alternative to natural aggregates (Kou & Poon, 2009).

METHODOLOGY

3.1 Materials

3.1.1 Cement

Ordinary Portland Cement (OPC) conforming to BS EN 197-1:2011, which specifies the composition, strength, and characteristics of common cement types was used.

3.1.2 Aggregates

Recycled Aggregates (RA): Aggregates obtained from crushed concrete waste, with a particle size distribution conforming to BS EN 12620:2002+A1:2008 for aggregates in concrete. Natural Fine Aggregate (Sand): River sand with a particle size distribution conforming to BS EN 12620:2002+A1:2008

3.1.3 Water

Clean potable water, free from impurities, meeting the requirements of BS EN 1008:2002 sources from the laboratory was used for this research.

3.1.4 Cement Slurry

Cement slurry of composition: A 1:1 (cement: water) ratio by weight was used, which was applied to the recycled aggregates in the cement slurry-treated group.

3.2 Mix Proportioning

The concrete mix design was based on achieving a target compressive strength of 25 KN/mm² at 28 days. The mix design was developed following the guidelines of BS 8500-1:2015, which provides recommendations for mix proportioning of concrete, ensuring the correct workability and strength are achieved.

The water-cement ratio (w/c) was kept constant at 0.50 for all concrete mixes to allow for a valid comparison between the different aggregate treatments. The mix proportions (by weight) for cement, aggregates, and water were calculated based on the guidelines of BS EN 206:2013 for normal-weight concrete.

3.3 Treatment of Recycled Aggregates

3.3.1 Non-Treated Recycled Aggregates (NTRA)

These aggregates were used directly after crushing and sieving. They were not subjected to any pre-treatment before being used in the concrete mix.

3.3.2 Recycled Aggregates Pre-Soaked in Water (PTRA)

Recycled aggregates were soaked in clean water for 24 hours prior to mixing. Excess water was drained before mixing to ensure consistent moisture content, as recommended by BS EN 1097-6:2013 for determining the bulk density and water absorption of aggregates.

3.3.3 Recycled Aggregates Soaked in Cement Slurry (STRA)

Recycled aggregates were soaked in a cement slurry (1:1 by weight) for 24 hours. The slurry was allowed to coat the aggregates, which were then drained for a short period (15 minutes) before use in the concrete mix. This method was intended to reduce the porosity of the recycled aggregates and improve their bond with the cement matrix.

3.4 Concrete Mixing Procedure

Concrete was mixed in batches using a rotating drum mixer, following the guidelines provided in BS EN 12390-2:2009 for mixing and making test specimens. The procedure was as follows:

- i. **Weighing:** All materials (cement, aggregates, water) were weighed according to the calculated mix design.
- ii. **Dry Mixing:** Cement, fine aggregate, and recycled coarse aggregate were dry mixed for 2 minutes.
- iii. **Adding Water:** Water was added gradually, and the entire mixture was mixed for an additional 5 minutes to ensure uniformity.
- iv. **Mixing Time:** Total mixing time was 7 minutes.

3.5 Workability Test (Slump Test)

Workability of the fresh concrete was assessed using the slump test in accordance with BS EN 12350-2:2009. The slump cone was filled in three layers; each compacted with 25 strokes of the tamping rod. After removing the cone, the difference in height between the cone and the concrete sample was measured.

3.6 Casting and Curing of Concrete Specimens

Concrete cubes (150mm x 150mm x 150mm) were cast for the compressive strength test, while additional specimens were prepared for the durability tests. The casting procedure adhered to BS EN 12390-2:2009 for making and curing test specimens.

After casting, the specimens were covered with a damp cloth and left in the mold for 24 hours. They were then demolded and submerged in a water tank for curing, following the requirements of BS EN 12390-2:2009.

3.7 Compressive Strength Test

Compressive strength tests were conducted at 7, 14, and 28 days, following the procedure outlined in BS EN 12390-3:2009. The concrete cubes were tested using a compression testing machine. The load was applied at a constant rate until failure, and the maximum load recorded was used to calculate the compressive strength.

3.8 Durability Tests

3.8.1 Water Absorption Test

Water absorption test was performed on concrete specimens in accordance with BS 1881-122:2011. The specimens were oven-dried at 105°C for 24 hours, then immersed in water for 24 hours. The difference in mass before and after immersion was used to calculate the water absorption percentage.

3.8.2 Chemical Resistance Test

Chemical resistance was evaluated by immersing specimens in a 5% NaCl solution for 28 days, as outlined in BS EN 12390-9:2016. After immersion, specimens were tested for compressive strength and any visible deterioration due to chemical attack.

3.8.3 Data Analysis

Data from the experiments were analyzed using statistical software. The compressive strength, workability (slump), and durability (water absorption and chemical resistance) data were analyzed to determine the significance of differences between the different treatment methods. Analysis of variance (ANOVA) was used to identify statistically significant differences between the groups.

4.0 RESULTS AND DISCUSSION

4.1 Compressive Strength Results

The compressive strength of the concrete samples was tested on 7, 14, and 28 days. The results are presented in Table 4.1.

Table 4.1: Compressive Strength Results of Concrete Specimens (kN/mm²)

Treatment Method	7 days (kN/mm ²)	14 Days (kN/mm ²)	28 Days (kN/mm ²)
NTRA	18.5	22.0	24.8
PTRA	19.7	23.4	26.1
STRA	21.5	26.0	29.3

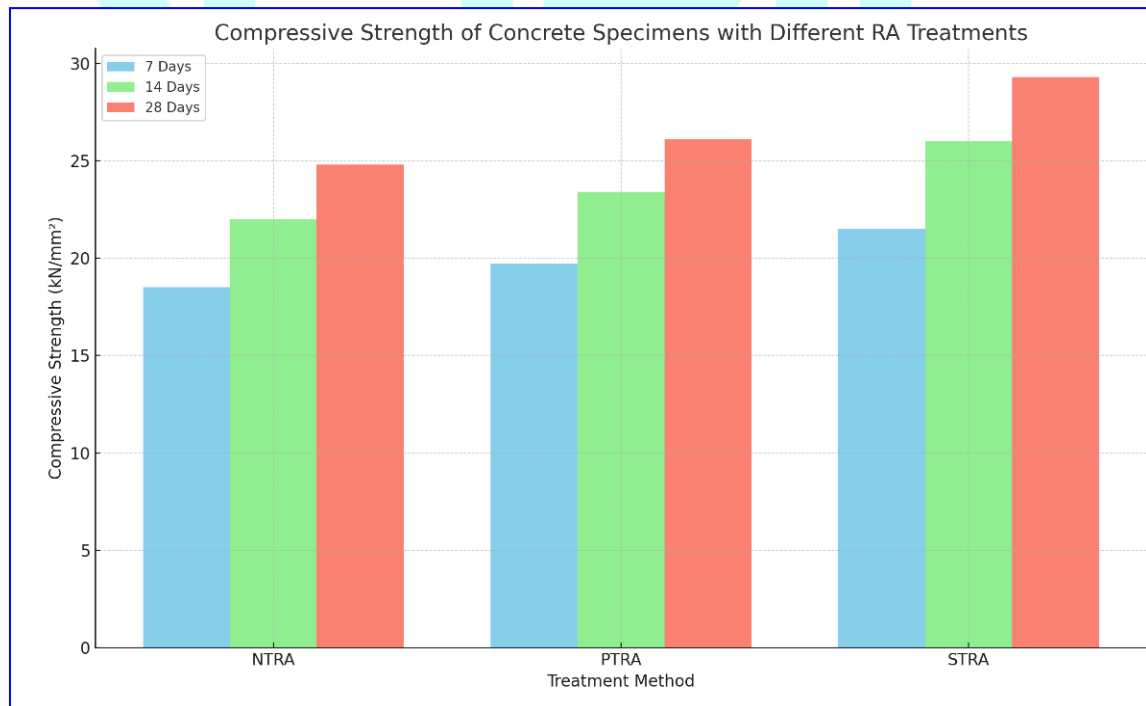


Fig 4.1 Compressive Strength of Concrete Specimens with Different Recycled Aggregate Treatment Methods

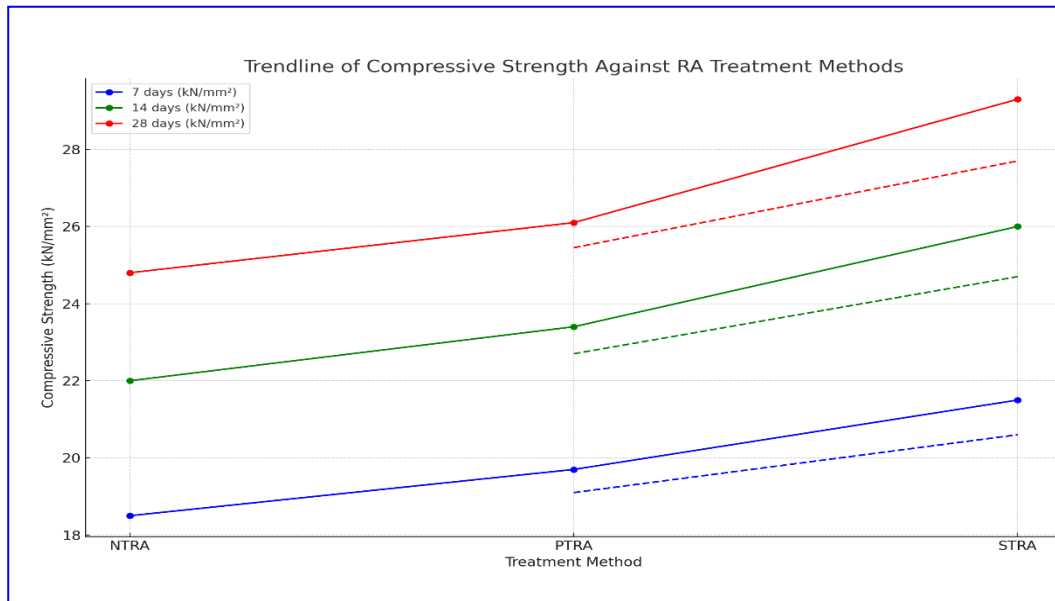


Fig 4.2 Trendline of Compressive strength and Recycled Aggregate Treatment Methods

The results show that the compressive strength of concrete made with recycled aggregates increases with the treatment of the aggregates. Concrete using non-treated recycled aggregates (NTRA) had the lowest compressive strength at all ages, with a 28-day strength of 24.8 KN/mm². This is consistent with previous studies, which have shown that the use of untreated recycled aggregates.

And tend to weaken the interfacial transition zone (ITZ) between the aggregate and the cement paste, leading to reduced strength. Pre-soaking the recycled aggregates in water (PTR A) improved the compressive strength by approximately 5.2% compared to the NTRA group. The pre-soaking likely reduced the water absorption of the aggregates during mixing, thereby improving the overall water-cement ratio and the bond between the aggregates and the cement paste.

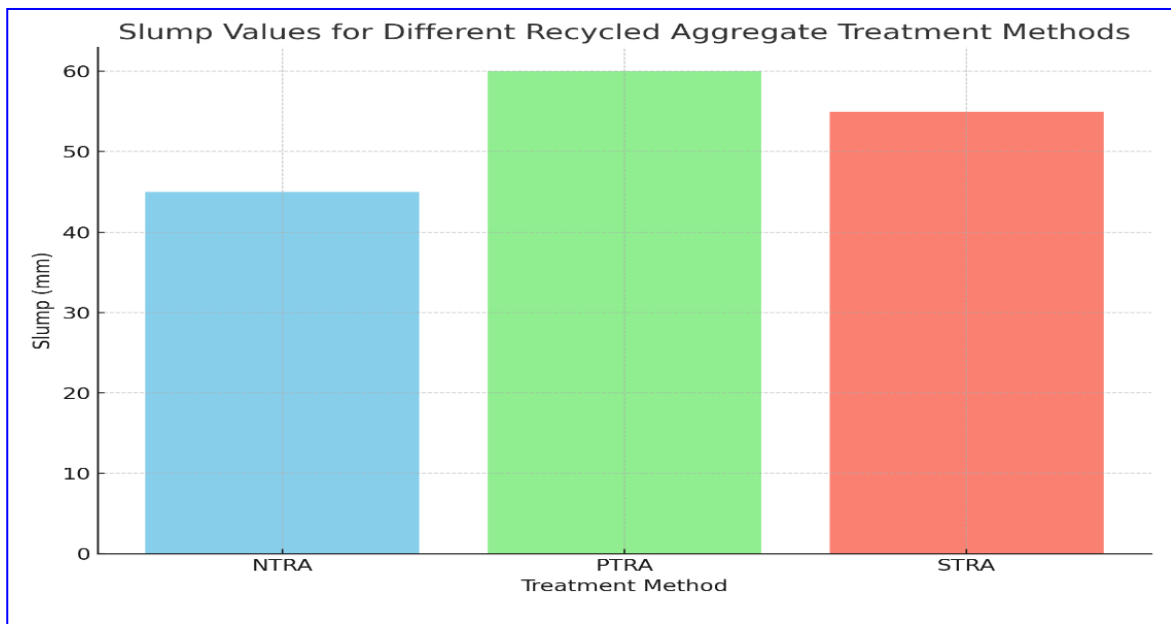
The best performance was observed for the concrete using recycled aggregates soaked in cement slurry (STR A). The 28-day compressive strength for STR A was 29.3 MPa, which is 18.1% higher than NTRA and 12.3% higher than PTR A. This result aligns with findings by Li et al. (2014), which reported that cement slurry treatments improve the strength of recycled aggregate concrete by creating a more cohesive ITZ.

4.3 Workability Results (Slump Test)

Workability was assessed using the slump test for all three concrete mixes. The results are summarized in Table 4.2.

Table 4.2: Slump Values for Fresh Concrete (mm)

Treatment Methods	Slump(mm)
NTRA	45
PTRA	60
STRA	55

**Fig 4.3** Slump values for different Recycled Aggregate Treatment

4.3.1 Discussion of Workability Results

The workability of concrete made with non-treated recycled aggregates (NTRA) was the lowest, with a slump of 45 mm. This lower workability is due to the higher water absorption of the untreated recycled aggregates, which reduces the amount of free water available for lubrication during mixing. Pre-soaking the recycled aggregates in water (PTRA) improved the workability significantly, achieving a slump of 60 mm. The increased workability is likely due to the saturated surface of the aggregates, which reduced water absorption during mixing. Interestingly, the slump of the STRA group was slightly lower than that of the PTRA group (55 mm). While the cement slurry treatment improved the aggregate properties, the coating of cement on the aggregate particles may have increased the friction between particles, reducing workability slightly compared to the pre-soaked group. Nonetheless, the STRA mix still exhibited better workability than the NTRA group, indicating that the treatment had a positive effect

4.4 Durability Results

4.4.1 Water Absorption Test

The water absorption test results are shown in Table 4.3.

Table 4.3: Water Absorption of Concrete Specimens (%)

Treatment Method	Water Absorption (%)
NTRA	6.2
PTRA	5.6
STRA	4.8

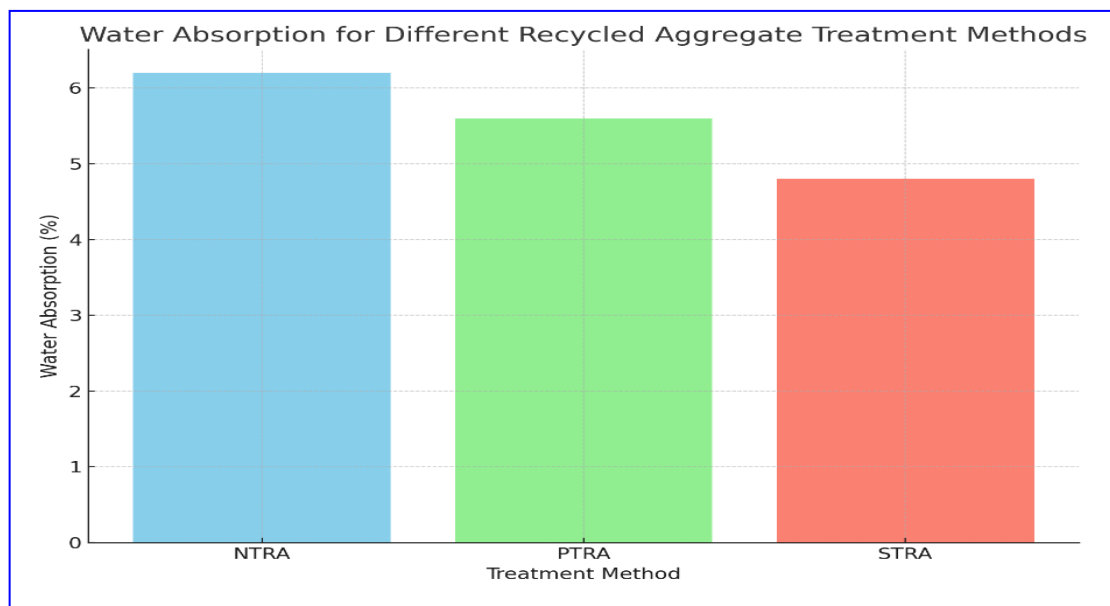


Fig 4.4 Water Absorption for Different Recycled Aggregate Treatment Methods

The water absorption of concrete made with NTRA was the highest at 6.2%, indicating higher porosity and reduced durability. Concrete with PTRA showed improved performance with a lower absorption rate of 5.6%, demonstrating that the pre-soaking treatment reduced porosity by filling the aggregate pores with water prior to mixing.

STRA had the lowest water absorption at 4.8%, which suggests that the cement slurry treatment effectively sealed the pores in the recycled aggregates. This result is consistent with studies by Silva et al. (2016), which showed that cement slurry treatments significantly reduce water absorption by improving the aggregate-cement bond.

4.4.2 Chemical Resistance Test

The chemical resistance results, shown in Table 4.4, were based on the residual compressive strength after immersion in a 5% NaCl solution for 28 days.

Table 4.4: Residual Compressive Strength after Chemical Exposure (KN/mm²)

Treatment Method	Residual Strength (KN/mm ²)
NTRA	21.3
PTRA	22.5
STRA	25.0

STRA exhibited the highest residual strength, showing superior resistance to chemical attack, likely due to the dense cementitious coating on the aggregate surfaces, which protected the concrete matrix from chloride penetration.

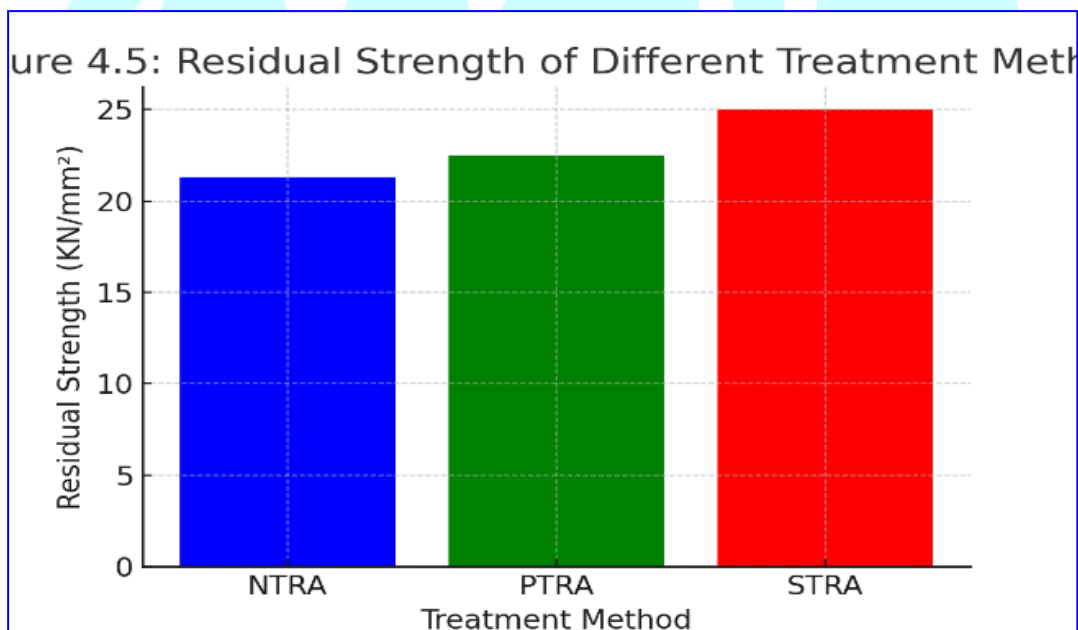


Figure 4.5: Residual Strength of Different Treatment Methods

It can be observed on the NTRA treatment method resulted in the lowest residual strength (21.3 KN/mm²), indicating that untreated aggregates negatively impact the structural integrity of concrete. On the PTRA the residual strength improved to 22.5 KN/mm², suggesting that pre-soaking in water helps mitigate the negative effects of recycled aggregates by reducing water absorption during mixing. STRA showed the highest residual

strength (25.0 KN/mm²), demonstrating that slurry treatment effectively enhances the bonding quality and density of the recycled aggregate, leading to improved concrete performance.

The bar chart clearly indicates that treatment methods positively influence residual strength, with slurry treatment being the most effective.

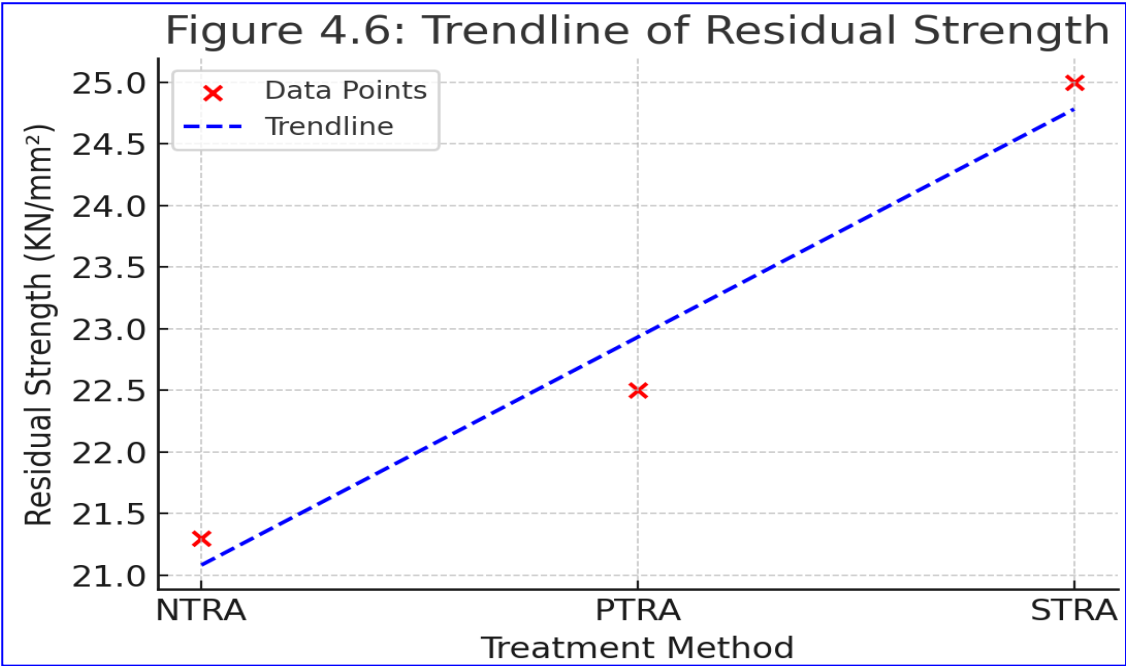


Figure 4.6: Trendline of Residual Strength

The trendline graph illustrates the relationship between different treatment methods and their corresponding residual strengths. The trendline shows an upward progression, suggesting that improved treatment methods result in higher residual strengths. The graph exhibits a linear increasing trend, indicating that as the level of treatment improves (from untreated to slurry-treated), the residual strength consistently increases. The slope of the trendline signifies the rate of improvement, emphasizing that slurry treatment has the most significant impact compared to pre-soaking. The correlation between treatment methods and residual strength appears strong, reinforcing the need for proper recycled aggregate treatment to enhance concrete performance.

The results of this study indicate that the treatment of recycled aggregates significantly improves the compressive strength, workability, and durability of recycled aggregate concrete. Cement slurry treatment (STRA) produced the best overall performance, offering

superior compressive strength, lower water absorption, and better resistance to chemical attack. Pre-soaking in water (PTRA) also improved the performance of the concrete, though not as effectively as the cement slurry treatment. Non-treated recycled aggregates (NTRA) consistently exhibited the weakest performance across all tests. These findings are consistent with previous research and highlight the potential of using treated recycled aggregates to enhance the sustainability and performance of concrete in structural applications.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1.1 Compressive Strength: Concrete made with untreated recycled aggregates (NTRA) had the lowest compressive strength at all ages, while concrete with recycled aggregates treated with cement slurry (STRA) had the highest strength, showing an improvement of 18.1% over NTRA. The cement slurry treatment provided better bond strength between the aggregates and the cement matrix, enhancing the interfacial transition zone (ITZ).

5.1.2 Workability: The workability of RAC was improved by the pre-treatment of recycled aggregates. Pre-soaking the aggregates in water (PTRA) produced the highest slump value, but the cement slurry treatment (STRA) offered a balance between improved workability and strength. This suggests that both treatments mitigate the issues of higher water absorption typically associated with recycled aggregates.

5.1.3 Durability: Cement slurry-treated concrete (STRA) showed the lowest water absorption, highest chemical resistance, indicating superior durability compared to both non-treated and water pre-soaked aggregates. The cement slurry likely filled the pores of the recycled aggregates, creating a denser, more impermeable concrete structure.

In conclusion, treating recycled aggregates with cement slurry significantly enhances the overall performance of recycled aggregate concrete in terms of compressive strength, workability, and durability. This method provides a viable solution to improving the quality of RAC, making it more suitable for structural applications, thus contributing to sustainable construction practices.

5.2 Recommendations

Based on the findings of this research, the following recommendations are proposed:

- i. **Adoption of Cement Slurry Treatment for Structural Concrete:** For applications where high strength and durability are critical, such as load-bearing structures, cement slurry-treated recycled aggregates (STRA) should be used. This method improves both mechanical properties and durability, making RAC more competitive with natural aggregate concrete.
- ii. **Pre-Soaking for Non-Structural Applications:** In cases where moderate strength and workability are sufficient, pre-soaking recycled aggregates in water (PTRA) offers an economical alternative to cement slurry treatment, especially for non-structural or secondary concrete applications.
- iii. **Standardization and Best Practices:** It is recommended that industry standards (such as BS codes) include guidelines for the pre-treatment of recycled aggregates, particularly the use of cement slurry, to enhance recycled aggregate concrete's performance. Additionally, concrete producers should implement standardized treatment processes for recycled aggregates to ensure consistency and quality.

5.3 Further Research

While this study provides valuable insights into the effects of aggregate treatment on RAC, further research is needed to explore other aspects of recycled aggregate concrete and improve its adoption in the construction industry. The following areas are suggested for future research:

- i. **Long-Term Performance of RAC:** Future studies should investigate the long-term performance of recycled aggregate concrete treated with cement slurry and water pre-soaking, particularly under real environmental conditions such as varying temperatures, moisture, and loadings.
- ii. **Optimization of Cement Slurry Composition:** Further research is recommended to optimize the composition of the cement slurry used in treating recycled aggregates. Variations in the water-cement ratio, cement type, and additives may provide better performance while reducing costs.
- iii. **Investigation of Alternative Treatment Methods:** Other treatment methods such as carbonation, polymer coatings, or nanomaterial treatments could be explored to

further enhance the properties of recycled aggregate concrete. These alternatives could provide new insights into cost-effective and environmentally friendly treatments.

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