Combined Effect of Water-Reducing Admixture and Recycled Fine Aggregate on the Workability of Concrete

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Abstract

Concrete workability is a crucial factor in ensuring the quality and durability of construction projects. This study investigates the effect of recycled fine aggregates (RFAs) and water-reducing admixtures (WRAs) on the slump value of concrete. The slump test was conducted to assess the workability of concrete mixes with varying levels of RFAs replacement (0%, 50%, 75%, and 100%). The results indicate that the incorporation of RFAs and WRAs improves the slump value compared to conventional concrete made with natural fine aggregates (NFAs). At 0% replacement, the slump increased from 85 mm (NFAs) to 95 mm (NFAs + WRAs). Further increments in RFAs replacement resulted in higher slump values, reaching a peak of 115 mm at 75% replacement before slightly decreasing to 110 mm at 100% replacement. These findings suggest that using RFAs with WRAs can enhance the workability of concrete, making it a viable alternative for sustainable construction practices.

Keywords: Slump Value, Workability, Recycled Fine Aggregates, Water-Reducing Admixtures, Concrete Mix Design.

1. Introduction

Concrete remains the most widely used construction material due to its strength, durability, and availability. However, the depletion of natural fine aggregates (NFAs) and environmental concerns have led to the exploration of sustainable alternatives. Recycled fine aggregates (RFAs), derived from demolished concrete waste, offer a viable solution but tend to affect workability due to their porous nature. To counteract this, water-reducing admixtures (WRAs) can be used to improve slump while maintaining strength and durability. This study evaluates the effect of RFAs and WRAs on concrete workability through slump value measurements.

Several studies have explored the use of recycled aggregates in concrete. Neville (2011) emphasized the impact of aggregate quality on concrete performance, highlighting the need for admixtures to improve workability. Mehta and Monteiro (2014) demonstrated that recycled aggregates tend to have a higher water absorption rate, which can reduce workability unless compensated with WRAs. Recent studies (ASTM C143, 2015) indicate that the combination of RFAs and WRAs can enhance slump while maintaining structural integrity. However, the optimal replacement levels for RFAs remain a subject of research.

Previous studies have mainly focused on coarse recycled aggregates, with limited research on fine aggregates. Additionally, most research lacks a detailed assessment of the combined effects of RFAs and WRAs on workability. There is a need to determine the optimal RFAs replacement level that maximizes workability without compromising other properties of concrete.

2. Objective of the Study

- To evaluate the effect of different RFA replacement levels on the slump value of concrete.
- To determine the effectiveness of WRAs in enhancing workability when using RFAs.
- To identify the optimal RFA replacement percentage that balances workability and sustainability.

3. Materials Properties

3.1. Cement (Binder)

The primary binding agent in concrete is Ordinary Portland Cement (OPC), specifically Kohat Cement (43 grade), which complies with ASTM or IS standards. According to ASTM guidelines, the fineness of cement is assessed using ASTM C204 (Standard Test Methods for Fineness of Hydraulic Cement by Air Permeability Apparatus) or ASTM C430. The specific gravity of the cement, recorded as 3.14, is determined following ASTM C188 (Standard Test Method for Density of Hydraulic Cement). Since cement undergoes a chemical reaction with water rather than absorbing it, its water absorption is labelled as "Not Applicable (NA)", as per ASTM C150 (Standard Specification for Portland Cement). The bulk density of the cement, measured at 1440 kg/m³, is also determined according to ASTM C188, which provides guidelines for evaluating the density of hydraulic cement for mix proportioning and storage. Adhering to these ASTM standards ensures consistency in cement characteristics, supporting quality control in concrete manufacturing. Shown in Table 1.

3.2. Fine Aggregate (FA) - Sand

Fine aggregate, primarily consisting of natural river sand and recycled materials from demolished plaster and concrete, is an essential component in concrete mixtures. Particles passing through a 4.75mm sieve are classified as fine aggregates. The sand used follows ASTM standards and exhibits key properties that influence concrete performance. According to ASTM C136, the fineness modulus is 2.60, signifying a well-graded particle size distribution that enhances workability. The specific gravity, determined using ASTM C128, is 2.67, representing its relative density compared to water, which plays a role in mix proportions. Water absorption, tested in accordance with ASTM C128, is 2.00%, indicating minimal moisture retention that affects the water-cement ratio. The bulk density, measured as per ASTM C29/C29M, is 1584 kg/m³, reflecting its mass per unit volume an important factor in mix design. Compliance with ASTM standards ensures the consistency and quality of sand in concrete applications. Shown in **Table 1.**

3.3. Recycled Fine Aggregates (RFAs)

Recycled fine aggregates (RFAs) are obtained from crushed plaster and concrete waste, which is then sieved through a 4.5mm mesh. The characteristics of RFAs are assessed using ASTM testing methodologies. As per ASTM C136, their fineness modulus is 2.80, indicating a particle distribution closer to that of cement. The specific gravity, tested according to ASTM C128, is 2.52, which is lower than that of natural sand, affecting proportioning in concrete mixtures. Water absorption, measured under ASTM C128, is 3.97%, significantly higher than natural sand due to the porous structure of RFAs, necessitating adjustments in the water-cement ratio. Additionally, the bulk density, determined following ASTM C29/C29M, is 1358 kg/m³, lower than natural sand, influencing concrete density and mix proportions. These characteristics highlight the need for tailored mix designs when integrating RFAs into concrete production. Shown in **Table 1.**

3.4. Coarse Aggregate (CA)

Coarse aggregates, consisting of crushed stone particles that pass through a 19mm sieve but are retained on a 4.75mm sieve, provide strength and bulk to concrete mixtures. Their properties, tested according to ASTM standards, ensure structural stability and performance. The fineness modulus, assessed as per ASTM C136, is 2.60, indicating appropriate gradation for effective load-bearing capacity. The specific gravity, measured under ASTM C127, is 2.65, signifying a higher density than sand but lower than cement. Water absorption, evaluated according to ASTM C127, is 1.00%, indicating lower moisture retention compared to RFAs but slightly higher than cement, which influences the mix design. The bulk density, determined using ASTM C29/C29M, is 1650 kg/m³—the highest among the aggregate materials—significantly contributing to the concrete's weight and structural integrity. These properties emphasize the role of coarse aggregates in enhancing the strength and durability of concrete structures. Shown in **Table 1.**

Table 1: Show the Properties of Cement, FA, RFAs and CA.

Properties	Binder - Cement	FA - Sand	FA - RFAs	CA
Fineness Modulus	2.80	2.60	2.80	2.60
Specific Gravity	3.14	2.67	2.52	2.65
Water Absorption	NA	2.00	3.97	1.00
Bulk Density kg/m^3	1440	1584	1358	1650

3.5. Water

Potable water free from impurities. Water plays a crucial role in various industrial and construction applications, and its properties are evaluated using specific ASTM standards. The **density** of water, measured as per **ASTM D1475,** is 1.01 g/cm^3, which falls within the acceptable range of 1.0-1.02 g/cm^3, ensuring consistency in composition. The **solid content**, tested according to **ASTM D2939,** is 43%, indicating the presence of dissolved or suspended solids within the acceptable range of 40%-50%. The **pH value**, determined using **ASTM E70,** is 8.0, classifying the water as slightly alkaline, which is within the standard range of 7-10. These properties influence water's suitability for applications such as concrete mixing, coatings, and industrial processes, Shown in Table 2.

Table 2: Show the Properties of Water.

Test	Value	Range (IS)	ASTM Standard	ASTM Range
Density	1.01 g/cm^3	1.0-1.02 g/cm^3	ASTM D1475	1.0-1.2 g/cm^3
Solid Content	43%	40%-50%	ASTM D2939	40%-50%
PH Value	8.0	8-10	ASTM E70	7-10

3.6. Water-Reducing Admixture (WRAs)

High-range water-reducing admixtures (superplasticizers) to improve workability without increasing water content. i.e. Max Flo P, Shown in **Table 3.**

Table 3: Show the Properties of WRAs.

Property	Test Method	Value
Component	-	Single
Form	-	Liquid
Colour	-	Dark Brown
Specific Gravity	ASTM C 494	1.16 +/- 0.02
Air Entrainment	ASTM C 231	Up to 2% Over Control Max
Chloride Content	BSEN 480-10	Nil to BSEN 934-2
pH	ASTM C 494	7-9

3.7. Grading of Aggregates

The grading of aggregate is a crucial factor to consider when replacing any material. In this study, the grading of recycled fine aggregate (RFA) was evaluated against natural sand. The results indicated that RFA exhibited characteristics similar to those of conventional aggregates, demonstrating comparable performance. This similarity in grading suggests that RFA can be a viable alternative to natural sand in construction applications, as shown in Fig. 1.

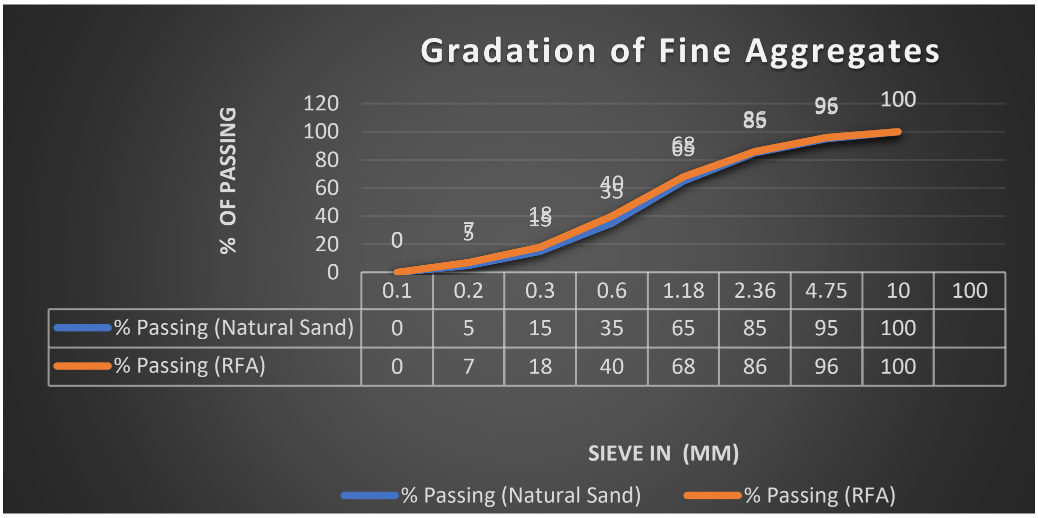

Fig. 1. Gradation of Fine Aggregates

3.8. Mix Design Proportion (Grade M15 = 1:2:4)

Concrete was designed with a constant water-cement ratio while varying the proportion of RFAs as replacements for NFAs at 0%, 50%, 75%, and 100%. The WRA dosage was maintained at 4% across all RFA-replaced mixes. Concrete mix design is a crucial process that determines the appropriate proportions of cement, fine aggregate, coarse aggregate, water, and admixtures to achieve the **desired workability and strength of concrete.** The concrete mix consists of different compositions based on the materials used and the water-cement (W/C) ratio. The first mix, labelled as **Normal Concrete**, includes cement, sand, and aggregate in a proportion of 1:2:4 with a W/C ratio of 0.7, without any water-reducing admixtures (WRAs). The second mix, **Normal Concrete with WRAs**, maintains the same material proportions (1:2:4) but reduces the W/C ratio to 0.5 while incorporating 4% WRAs to enhance workability and performance. The third mix, **RFA with WRAs Concrete**, also follows the 1:2:4 proportion, with a W/C ratio of 0.5 and 4% WRAs, but replaces natural fine aggregate with recycled fine aggregate (RFA), making it a more sustainable alternative. These variations allow for the optimization of strength, durability, and sustainability in concrete applications. Shown in **Table 4.**

Table 4: **Show Mix Design Proportion.**

Concrete	Cement	Fine Aggregate	Coarse Aggregate	W/C Ratio	WRAs
Normal Concrete	1	2	4	0.7	0%
Normal Concrete, WRAs	1	2	4	0.5	4%
RFAs Concrete, WRAs	1	2	4	0.5	4%

3.9. Effect of WRAs on Workability of NFAs

The graph illustrates the impact of water-reducing admixtures (WRAs) on the workability of concrete containing natural fine aggregates (NFAs). The slump value, which indicates concrete workability, is plotted on the y-axis, while the x-axis represents the proportion of natural fine aggregate used. The blue bar represents NFAs without WRAs, showing a slump value of 85 mm. In contrast, the orange bar represents NFAs mixed with 4% WRAs, resulting in an increased slump value of 95 mm. This indicates that the addition of WRAs significantly enhances the workability of concrete, making it more fluid and easier to handle. The increased slump value suggests that WRAs improve the flowability of the concrete mix, reducing the water demand while maintaining the desired consistency and strength. Shown in Fig. 2.

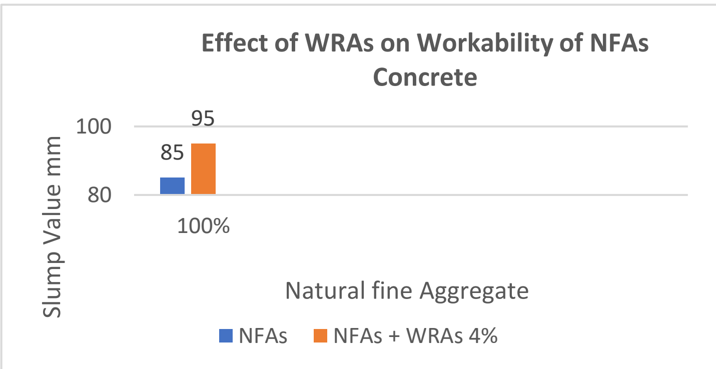

Fig. 2. **Effect of WRAs on Workability of NFAs Concrete**

4. Casting of Specimen

The specimen mixing process involved different combinations of natural fine aggregates (sand) and recycled fine aggregates (RFA) with and without water-reducing admixtures (WRAs). The first combination consisted of 100% sand with 0% RFA and no WRAs, resulting in three slump test samples. The second combination maintained 100% sand but incorporated 4% WRAs, also producing three slump test samples. In the third combination, the mix included 50% RFA and 50% sand with 4% WRAs, yielding three slump test samples. The fourth combination increased the RFA content to 75% while reducing sand to 25%, along with 4% WRAs, again resulting in three slump test samples. Finally, the last combination consisted entirely of 100% RFA with 4% WRAs and no natural sand, maintaining the trend of three slump test samples. These variations were designed to assess the impact of different RFA proportions and the presence of WRAs on the workability of concrete. Shown in **Table 5.**

Table 5: Show Casting of Specimen.

Specimen Mixing	Combinations	Workability Slump Test Samples (mm)
Normal Concrete	Sand 100% + RFA 0% + WRAS 0%	3
Normal Concrete, WRAs	Sand 100% + RFA 0% + WRAS 4%	3
RFA Concrete, WRAs	RFA 50% + Sand 50% + WRAs 4%	3
RFA Concrete, WRAs	RFA 75% + Sand 25% + WRAs 4%	3
RFA Concrete, WRAs	RFA 100% + Sand 0% + WRAs 4%	3

5. Workability (Slump Value Test)

The slump test was performed according to ASTM C143 to evaluate the workability of different mixes. The workability of different concrete mixtures was evaluated through slump tests. The Normal concrete mix, consisting of 100% sand with no recycled fine aggregate (RFA) or water-reducing admixtures (WRAs), exhibited a slump of 85 mm. When 4% WRAs were added to the same mix, the slump increased to 95 mm, indicating improved workability. Further modifications involved replacing sand with RFA while maintaining a 4% WRAs content. A mix with 50% RFA and 50% sand resulted in a slump of 105 mm, while increasing the RFA content to 75% led to a slump of 115 mm. However, when sand was completely replaced with 100% RFA, the slump slightly decreased to 110 mm. These results suggest that increasing RFA content generally enhances workability, though excessive replacement may reduce the effect.

Table 6: Show Workability of Specimen.

Specimen Mixing	Combinations	Samples	Workability Slump Test (mm)
Normal Concrete	Sand 100% + RFA 0% + WRAS 0%	3	85
Normal Concrete, WRAs	Sand 100% + RFA 0% + WRAS 4%	3	95
RFA Concrete, WRAs	RFA 50% + Sand 50% + WRAs 4%	3	105
RFA Concrete, WRAs	RFA 75% + Sand 25% + WRAs 4%	3	115
RFA Concrete, WRAs	RFA 100% + Sand 0% + WRAs 4%	3	110

The slump height was measured and recorded. The graph titled **"Slump Value Graph"** illustrates the relationship between **RFAs replacement** percentages and the corresponding **slump values (in mm)**. The **x-axis** represents the percentage of **RFAs replacement**, ranging from **0% to 100%**, while the **y-axis** represents the **slump value (in mm)**, ranging from **0 to 150 mm**. Two categories of data are displayed: **NFAs (Normal Fine Aggregates)** in **blue** and **RFAs + WRAs 4% (Recycled Fine Aggregates with Water-Reducing Admixtures at 4%)** in **orange**. At **0% replacement**, the slump value for **NFAs** is **85 mm**, whereas for **RFAs + WRAs 4%**, it is slightly higher at **95 mm**. As the **RFA replacement percentage increases**, the slump values continue to rise, reaching a peak of **115 mm at 75% replacement**. However, at **100% replacement**, the slump value slightly decreases to **110 mm**. This trend suggests that incorporating **RFAs with WRAs at 4%** enhances workability initially, but at full replacement, the slump value slightly declines. Shown in Fig. 3.

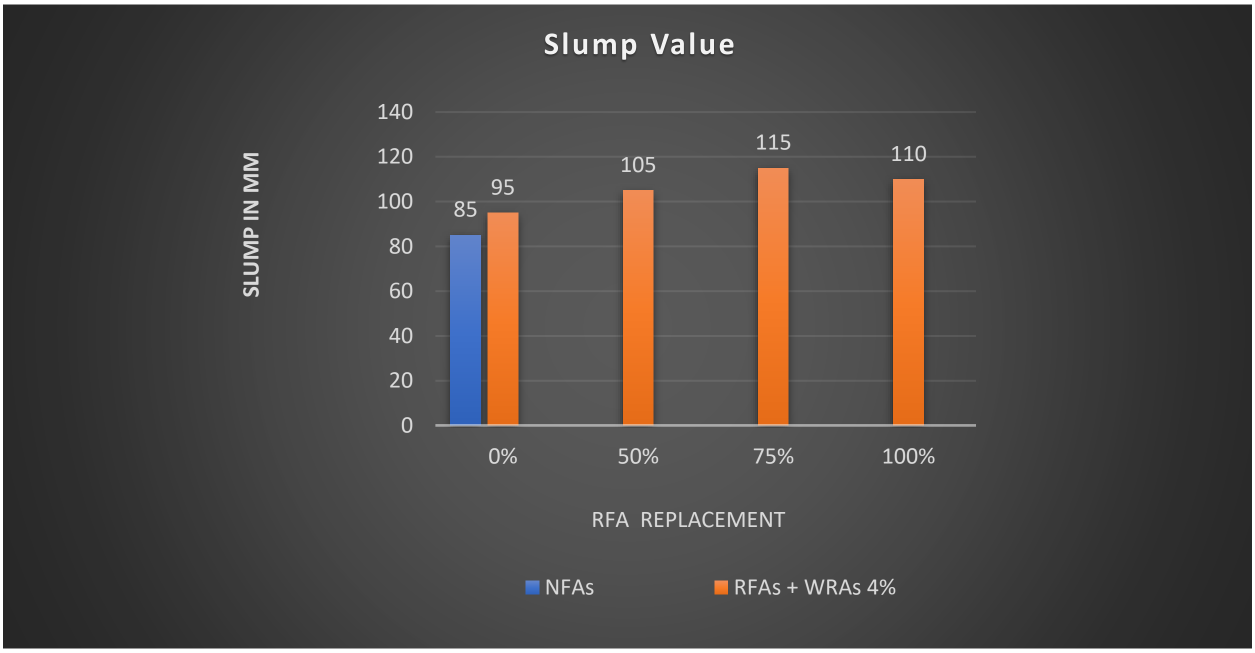

Fig. 3. Show the workability against different proportion of RFAs

6. Results and Discussion

The results of the slump test reveal a noticeable increase in slump value with the inclusion of RFAs and WRAs, indicating improved workability. At 0% replacement, the slump increased from 85 mm for NFA concrete to 95 mm when RFAs and WRAs were introduced, demonstrating a significant enhancement. As the replacement level increased to 50%, the slump value further rose to 105 mm, maintaining a positive trend. The highest slump value of 115 mm was observed at 75% replacement, suggesting that this level provided the optimal improvement in workability. However, at 100% replacement, the slump slightly decreased to 110 mm, which could be attributed to the increased water absorption capacity of RFAs, necessitating further optimization. This trend suggests that while RFAs contribute to better workability, excessive replacement may reduce effectiveness due to higher water demand. The combined effect of RFAs and WRAs offers a promising approach for achieving sustainable and highly workable concrete

7. Conclusion

Workability Enhancement

Incorporating Recycled Fine Aggregates (RFAs) with Water-Reducing Admixtures (WRAs) significantly improves the workability of concrete. This improvement is evident in the increased slump values, which measure the concrete's consistency and ease of placement.

Optimal Replacement Level

The study identifies that an RFA replacement level of approximately 75% provides the best workability results. At this level, the slump values are maximized, indicating a highly workable concrete mix. However, when the RFA content exceeds 75%, a slight decline in the slump is observed, suggesting a potential limitation in further increasing RFA content.

Sustainable Alternative

The results demonstrate that RFAs, when combined with WRAs, can effectively replace Natural Fine Aggregates (NFAs) without significantly reducing workability. This suggests that RFAs, in conjunction with WRAs, present a sustainable and eco-friendly alternative to traditional NFAs.

Future Research Directions

Further studies should investigate the effects of RFAs on concrete strength, durability, and long-term performance. This research would help determine the structural reliability and practical applicability of RFAs in various construction scenarios.

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