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EXPERIMENTAL STUDY OF THE EFFECT OF WATER-REDUCING ADMIXTURE AND RECYCLED FINE AGGREGATE ON MECHANICAL PROPERTIES OF CONCRETE

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Abstract
The utilization of recycled fine aggregate (RFA) in concrete has gained significant attention due to its potential to reduce environmental impact and conserve natural resources. However, the incorporation of RFA often leads to a reduction in the mechanical properties of concrete. This study investigates the combined effect of water-reducing admixture (WRA) and RFA on the compressive and tensile strength of concrete. The experimental program involved the preparation of concrete mixtures with varying proportions of RFA (0%, 50%, 75%, and 100%) and after trail for different dosages of WRA (2%, 3%, and 4% by weight of cement) and WRAs give good workability by use of 4% of WRAs. Compressive and tensile strengths were evaluated at 28 days. The results indicate that the addition of WRA significantly improves the workability and mechanical properties of RFA concrete. The optimal combination of 75% RFAs and 4% WRAs yielded the highest compressive and tensile strengths, demonstrating the potential for sustainable concrete production without compromising performance.

INTRODUCTION

Concrete is the most widely used construction material globally, and its production consumes vast amounts of natural resources, particularly fine aggregates. The depletion of natural sand reserves and the environmental impact of mining have led to the exploration of alternative materials, such as recycled fine aggregate (RFA), derived from construction and demolition waste. However, the use of RFA in concrete often results in reduced mechanical properties due to its higher porosity and water absorption compared to natural fine aggregate (NFA).

Water-reducing admixtures (WRAs) are commonly used in concrete to improve workability and reduce water content, thereby enhancing strength and durability. This study aims to investigate the combined effect of WRA and RFA on the mechanical properties of concrete, specifically compressive and tensile strength. The findings will contribute to the development of sustainable concrete mixtures that utilize recycled materials while maintaining or improving performance.

Several studies have explored the use of RFA in concrete. [1] reported that the replacement of NFA with RFA up to 30% did not significantly affect the compressive strength of concrete, but higher replacement levels led to a noticeable reduction. [2] observed that the incorporation of RFA increased the water demand of concrete, necessitating the use of WRA to maintain workability. [3] demonstrated that the addition of WRA improved the mechanical properties of RFA concrete, with optimal performance achieved at a WRA dosage of 1.0%.

The combined effect of WRA and RFA on concrete properties has been less extensively studied. [4] investigated the influence of WRA on the compressive strength of RFA concrete and found that the use of WRA mitigated the strength reduction associated with RFA. [5] reported that the combination of WRA and RFA improved the tensile strength of concrete, with the highest strength achieved at a WRA dosage of 1.5%.

Despite extensive studies on RFA and WRAs, there remains a gap in understanding the optimal combination of these materials to achieve maximum strength and workability. While previous research has explored the individual effects of RFA and WRAs, limited studies have systematically investigated their combined influence. Furthermore, there is a lack of comprehensive experimental data on higher replacement levels of RFA (>50%) in conjunction with WRA dosages beyond standard recommendations. Addressing this gap can contribute to sustainable construction practices without compromising structural integrity.

2. Objectives

i. To evaluate the effect of varying proportions of RFA (0%, 50%, 75%, and 100%) on the compressive and tensile strength of concrete.
ii. To assess the impact of WRAs (4% by weight of cement) on the workability and mechanical properties of RFA concrete.
iii. To identify the optimal combination of RFA and WRA that yields the highest mechanical performance.
iv. To contribute to sustainable concrete production by proposing an effective mix design utilizing RFA and WRA.

3. Materials Properties

3.1. Cement (Binder)

Ordinary Portland Cement (OPC) Kohat Cement of 43 grades, conforming to ASTM or IS standards. Cement (Binder) is the primary binding material used in concrete. According to ASTM standards, the fineness of cement is determined by ASTM C204 (Standard Test Methods for Fineness of Hydraulic Cement by Air Permeability Apparatus) or ASTM C430. The specific gravity of cement, measured as 3.14, is determined using ASTM C188 (Standard Test Method for Density of Hydraulic Cement). Water absorption is marked as "NA" since cement does not absorb water but reacts chemically with it, as outlined in ASTM C150 (Standard Specification for Portland Cement). The bulk density of cement, which is 1440 kg/m³, is typically measured following ASTM C188, which provides guidelines for determining the density of hydraulic cement for mix proportioning and storage considerations. These ASTM standards ensure consistency in cement properties for quality control in concrete production. Shown in **Table 1.**

3.2. Fine Aggregate (FA) - Sand

Natural fine aggregate (river sand) and recycled fine aggregate sourced from demolished plaster and concrete structures. (Pass on Sieve 4.75mm). Sand, as a commonly used fine aggregate in concrete mixes, is characterized by several key properties as per ASTM standards. The fineness modulus, determined according to **ASTM C136**, is **2.60,** indicating a well-graded particle distribution that enhances workability. The specific gravity, measured following **ASTM C128,** is **2.67,** representing its density relative to water, which influences mix proportions. Water absorption, tested as per **ASTM C128,** is **2.00%,** meaning the sand can retain a small amount of water, impacting the water-cement ratio. The bulk density, evaluated in accordance with **ASTM C29/C29M,** is **1584 kg/m³,** signifying its mass per unit volume, which is crucial for mix design calculations. These ASTM standards ensure the quality and consistency of sand used in concrete applications. Shown in **Table 1.**

3.3. Recycled Fine Aggregates (RFAs)

RFAs are getting from the plaster and concrete waste, when collect and then crushed, after crushing then it is passed by 4.5mm sieve. According to ASTM standards, the properties of Recycled Fine Aggregates (RFAs) can be analyzed using various test methods. The **fineness modulus** of RFAs, measured as per **ASTM C136**, is **2.80**, indicating a fine particle size distribution similar to cement. The **specific gravity**, determined following **ASTM C128,** is **2.52,** which is lower than that of natural sand, impacting mix proportioning. The **water absorption,** tested according to **ASTM C128,** is **3.97**%, significantly higher due to the porous nature of RFAs, necessitating adjustments in the water-cement ratio. Lastly, the **bulk density**, measured as per **ASTM C29/C29M,** is **1358 kg/m³**, lower than that of sand, which influences mix design and concrete density. These properties highlight the importance of modifying mix designs when incorporating RFAs into concrete. Shown in **Table 1.**

3.4. Coarse Aggregate (CA)

Crushed stone aggregates of suitable size (Pass on sieve 19mm, And Retain on 4.75mm). Coarse aggregate (CA) plays a crucial role in providing strength and bulk to concrete. According to ASTM standards, its fineness modulus, determined as per **ASTM C136,** is 2.60, ensuring proper gradation for optimal load-bearing capacity. The specific gravity, measured following **ASTM C127**, is 2.65, indicating that it is denser than sand but lighter than cement. Water absorption, tested under **ASTM C127**, is 1.00%, showing it absorbs less water than recycled fine aggregates (RFAs) but more than cement, which influences the concrete mix design. The bulk density, assessed as per **ASTM C29/C29M,** is 1650 kg/m³, the highest among all materials, contributing significantly to the overall weight and structural integrity of concrete. Shown in **Table 1.**

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

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

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/cm³, which falls within the acceptable range of 1.0-1.02 g/cm³, 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.

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

3.6. 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.

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%

3.7. 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 (RFAs) was evaluated against natural sand. The results indicated that RFAs exhibited characteristics similar to those of conventional aggregates, demonstrating comparable performance. This similarity in grading suggests that RFAs can be a viable alternative to natural sand in construction applications, as shown in Fig. 1.

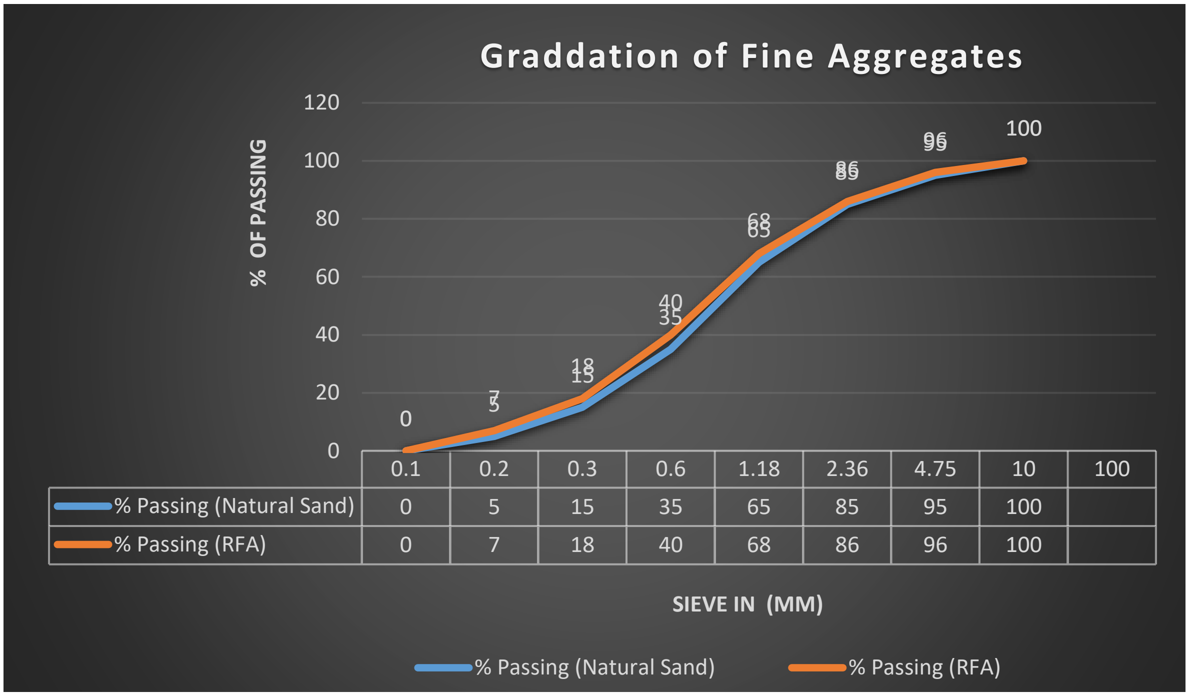


Fig. 1. Gradation of Fine Aggregates

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

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, labeled 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.**

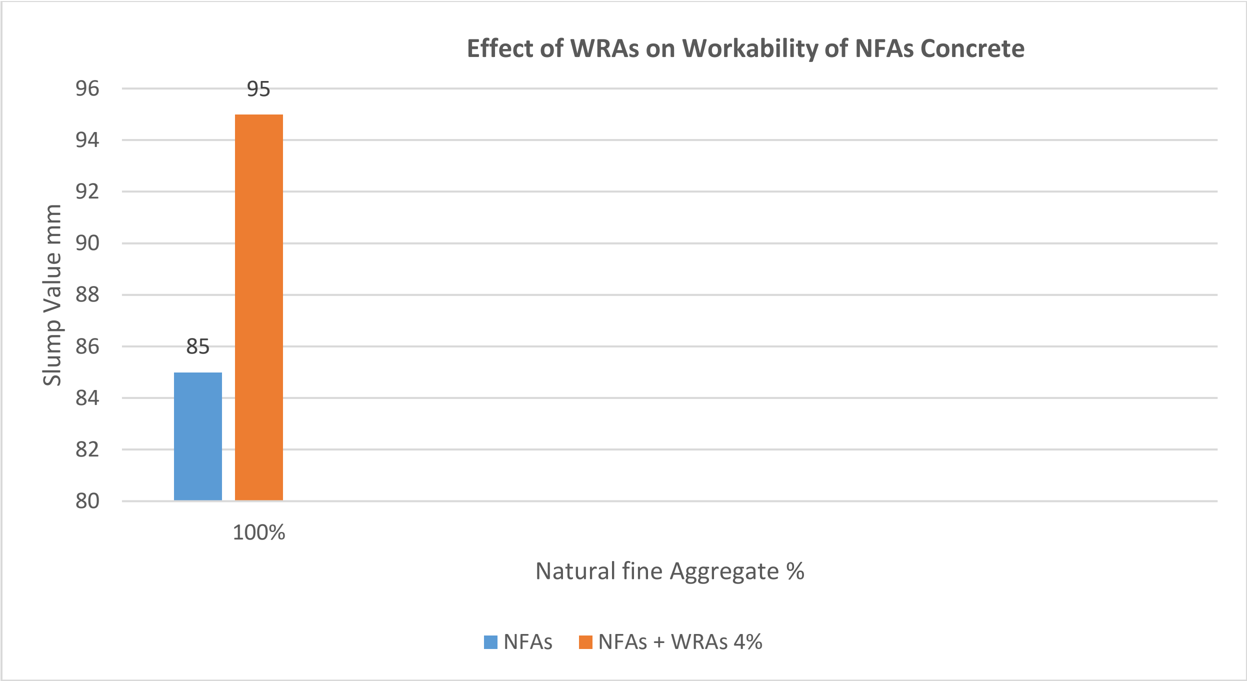
Table 4: Show Mix Design Proportion.

Property	Test Method	Value
Component	-	Single
Form	-	Liquid
Color	-	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

3.8. Effect of WRAs on Natural Fine Aggregates Concretes

The addition of water-reducing admixtures (WRAs) has a significant impact on the workability and compressive strength of concrete incorporating natural fine aggregates (NFAs). The slump value, which indicates the workability of the concrete, increases from 85 mm to 95 mm with the inclusion of WRAs at 4%, demonstrating improved flowability. This suggests that WRAs enhance the ease of placement and compaction of the concrete mix. Similarly, the compressive strength of the concrete also exhibits a notable improvement. Without WRAs, the compressive strength is recorded at 15.47 MPa, whereas with the inclusion of WRAs at 4%, it increases to 19.78 MPa. The bar chart illustrates the effect of Water-Reducing Admixtures (WRAs) on the tensile strength of Natural Fine Aggregates (NFAs) Concrete. The tensile strength of NFAs Concrete without WRAs is 1.43 MPa, while adding 4% WRAs increases it to 1.97 MPa. This increase in strength suggests that WRAs contribute to better particle packing and reduced water content, leading to enhanced hydration and overall strength development. Hence, the use of WRAs positively influences both workability and compressive strength, making the concrete mix more efficient and durable. Shown in **Fig 2,3 and 4.**

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



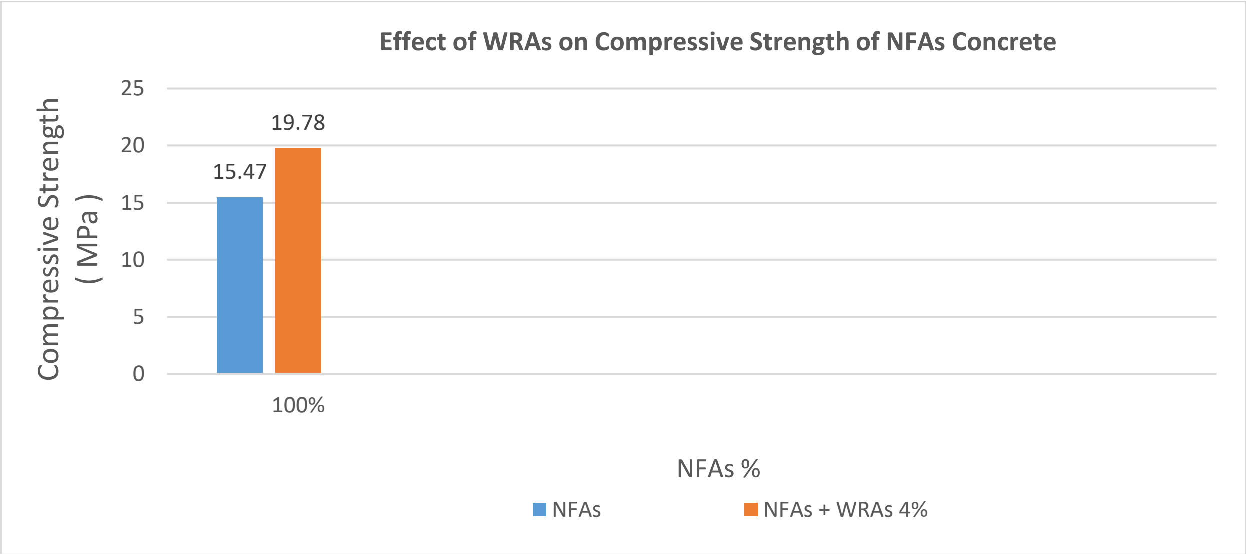


Fig. 3. Effect of WRAs on Compressive Strength of NFAs Concrete

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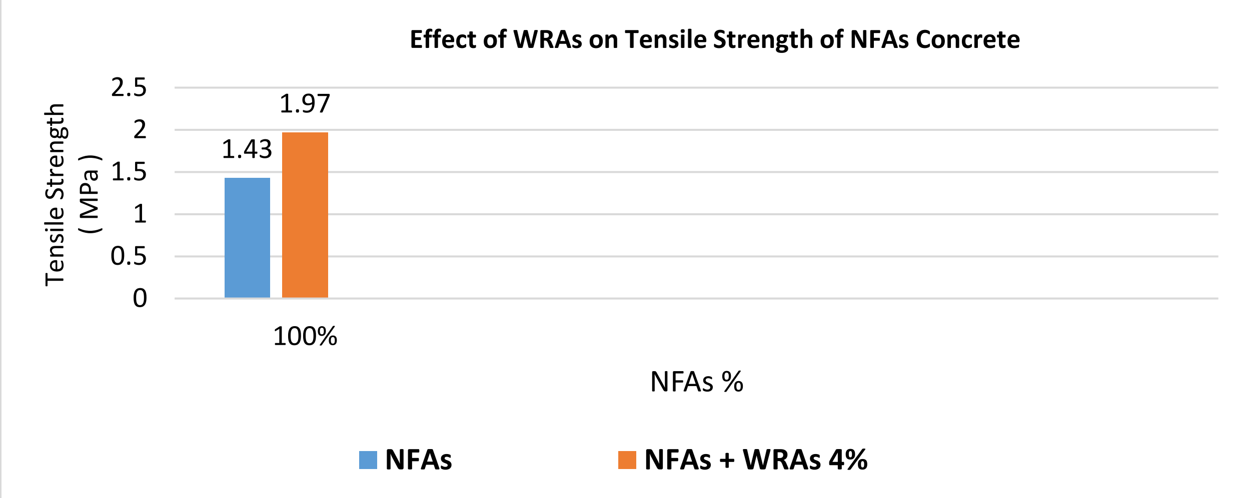

Fig. 4. Effect of WRAs on Tensile Strength of NFAs Concrete

4. Casting of Specimen

With the M15 grade mix proportions, sixth different combinations have been casted by using river sand, RFAs and WRAs. M15 concrete is a type of concrete mix with a characteristic compressive strength of 15 MPa (Megapascals) after 28 days of curing. The "M" in M15 stands for "Mix," and the number 15 indicates its strength in MPa. This mix is commonly used in non-structural applications such as pavements, flooring, and leveling surfaces, where high strength is not a primary requirement. The typical nominal mix ratio for M15 concrete is 1:2:4, which means 1-part cement, 2 parts sand (fine aggregate), and 4 parts coarse aggregate. Water is added as per the required workability to achieve the desired consistency and ease of placement.

The specimen mixing process involved different combinations of natural sand, recycled fine aggregate (RFA), and water-reducing admixtures (WRAs) to assess their impact on M15 concrete. Five mix combinations were tested: **Normal Concrete** (**100% Sand, 0% RFA, 0% WRAs**), **Normal Concrete with WRAs** (**100% Sand, 0% RFA, 4% WRAs**), **and three RFA-based** Concrete **mixes—50% RFA + 50% Sand + 4% WRAs, 75% RFA + 25% Sand + 4% WRAs, and 100% RFA + 0% Sand + 4% WRAs.**

For each mix**, compressive strength tests** were conducted on **cube samples** (**150 mm × 150 mm × 150 mm**)**, tensile strength tests** were performed on **cylindrical samples** (**150 mm diameter, 300 mm height**)**,** and **workability was assessed through slump tests.** A total of **three specimens** were prepared for each test across all mix designs, with testing conducted after **28 days of curing** to evaluate the concrete's performance.

To assess the workability of fresh concrete, a slump test should be conducted for each mix. This test will help evaluate the effects of water-reducing admixtures (WRA) and varying recycled fine aggregate (RFA) content on the slump values. Workability can be categorized into four ranges: very low (0-25mm), low (25-50mm), medium (50-100mm), and high (100-150mm).

For compressive strength testing, cube specimens of dimensions (150 mm × 150 mm × 150 mm) should be prepared and tested after 28 days of curing using a compression testing machine.

Additionally, for tensile strength assessment, cylindrical specimens with a (diameter of 150 mm and a height of 300 mm) should be prepared. These specimens should undergo compressive strength testing after 28 days of curing using a compression testing machine to determine their splitting tensile strength. Shown in **Fig 5**, **Table 5.**

Table 5: Show Casting of Specimen.

Specimen Mixing	Combinations	Samples Curing days	Compressive Strength Test Cubes Samples (MPa)	Tensile Strength Test Cylinders Samples (MPa)	Workability Slump Test Samples (mm)
Normal Concrete	Sand 100% + RFA 0% + WRAS 0%	28	3	3	3
Normal Concrete, WRAs	Sand 100% + RFA 0% + WRAS 4%	28	3	3	3
RFA Concrete, WRAs	RFA 50% + Sand 50% + WRAs 4%	28	3	3	3
RFA Concrete, WRAs	RFA 75% + Sand 25% + WRAs 4%	28	3	3	3
RFA Concrete, WRAs	RFA 100% + Sand 0% + WRAs 4%	28	3	3	3

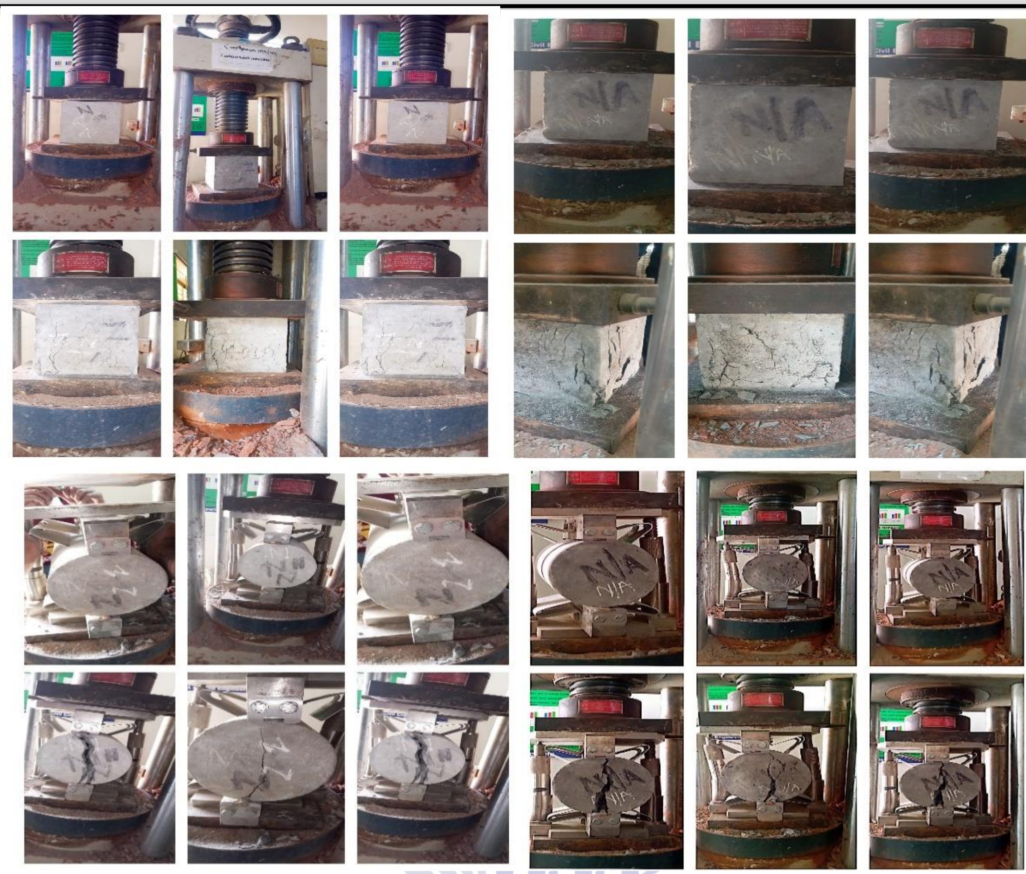

Fig 5: Show the Cast of specimens

5. Specimen Testing

The table presents data on the effects of different concrete mix compositions on **compressive** strength, tensile strength, and workability. It examines five different mix designs, incorporating varying proportions of Recycled Fine Aggregate (RFA), Sand, and Water-Reducing Admixtures (WRAs).

The first mix, Normal Concrete, contains 100% sand with no RFA or WRAs, resulting in a compressive strength of 15.47 MPa, a tensile strength of 1.43 MPa, and a workability slump of 85 mm. When WRAs were added to the same mix (Normal Concrete with WRAs), the compressive strength increased to 19.78 MPa, the tensile strength improved to 1.97 MPa, and workability increased to 95 mm, demonstrating the positive impact of WRAs on concrete properties.

As RFA was introduced, replacing portions of sand while maintaining 4% WRAs, the strength and workability further improved. With 50% RFA and 50% sand, the compressive strength rose to 22.34 MPa, the tensile strength significantly increased to 3.28 MPa, and workability reached 105 mm. When the RFA proportion was increased to 75%, the compressive strength peaked at 28.03 MPa, the tensile strength slightly increased to 3.37 MPa, and workability improved to 115 mm.

However, when 100% RFA was used, there was a slight decrease in compressive strength to 26.35 MPa and a minor reduction in tensile strength to 3.31 MPa, with a workability slump of 110 mm. This suggests that while replacing sand with RFA enhances mechanical properties up to a certain level, a complete replacement may slightly reduce compressive and tensile strength.

Overall, the findings highlight that incorporating RFA and WRAs improves concrete performance, particularly at an optimal RFA replacement of 75%, which yields the highest compressive strength and workability. However, full RFA replacement may result in a marginal decline in strength properties. Shown in Table 6.

Table 6: Show Specimen Testing

Specimen Mixing	Combinations	Samples	Compressive Strength Test Cubes (MPa)	Tensile Strength Test Cylinders (MPa)	Workability Slump Test (mm)
Normal Concrete	Sand 100% + RFA 0% + WRAS 0%	3	15.47	1.43	85
Normal Concrete, WRAs	Sand 100% + RFA 0% + WRAS 4%	3	19.78	1.97	95
RFA Concrete, WRAs	RFA 50% + Sand 50% + WRAs 4%	3	22.34	3.28	105
RFA Concrete, WRAs	RFA 75% + Sand 25% + WRAs 4%	3	28.03	3.37	115
RFA Concrete, WRAs	RFA 100% + Sand 0% + WRAs 4%	3	26.35	3.31	110

5.1. Fresh Concrete Test

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. 6.

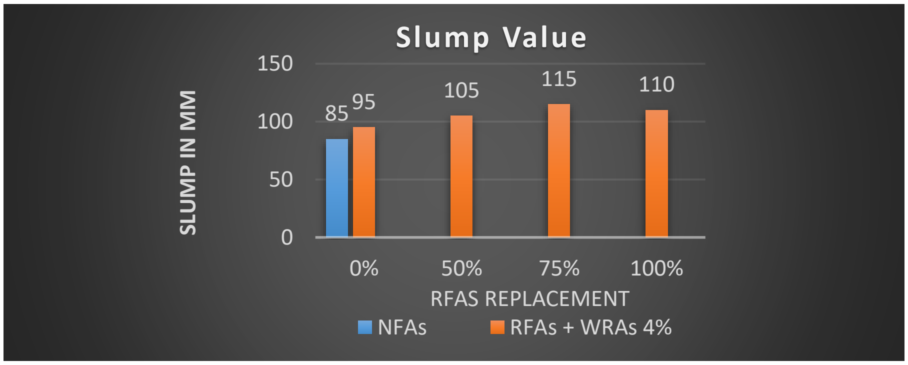

Fig. 6. Show the workability against different proportion of RFAs

5.2. Compressive Strength

The compressive strength of RFAC was evaluated using cubes cured for 28 days. Results indicate that up to 75% replacement of natural fine aggregates (RFAs) enhances strength, with the highest compressive strength of 28.03 MPa observed at 75% replacement. At 0% replacement, the lowest strength of 15.47 MPa was recorded, while 50% replacement increased it to 22.34 MPa. At 100% replacement, strength slightly declined to 26.35 MPa, though still higher than 0% and 50%. These findings suggest that incorporating RFAs improves concrete properties, with 75% replacement being optimal. Full replacement, however, may lead to a minor strength reduction. Shown in **Fig. 7.**

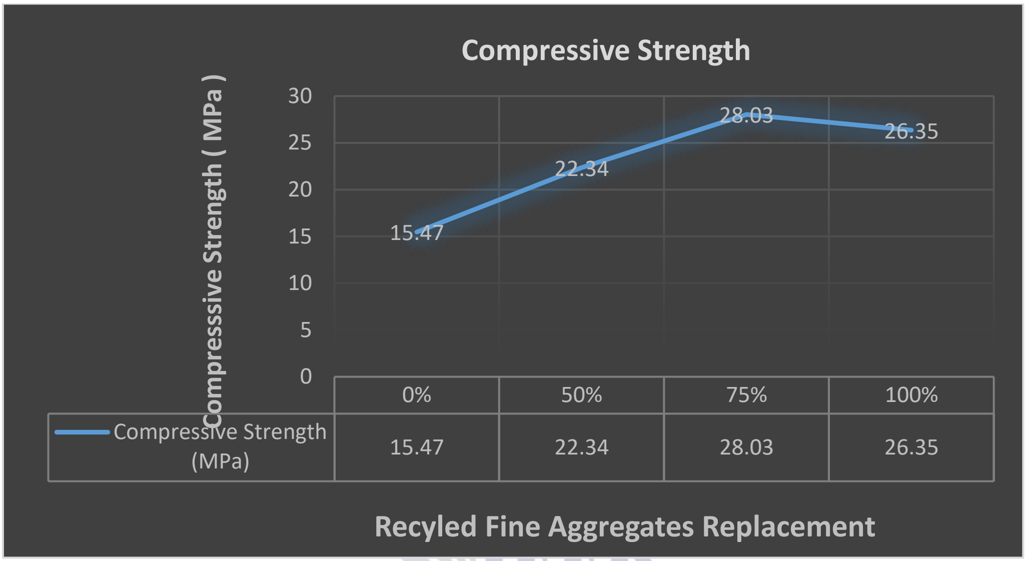

Fig. 7. Show the compressive strength against different proportion of RFAs

5.3. Split Tensile Strength

The split tensile strength of Recycled Fine Aggregate Concrete (RFAC) was evaluated using cylindrical specimens cured for 28 days. The results indicate that replacing up to 75% of natural fine aggregates (NFAs) with RFAs significantly improves tensile strength compared to conventional concrete. At 0% RFA replacement, the tensile strength is lowest (1.43 MPa). A 50% replacement leads to a substantial increase (3.28 MPa), while 75% replacement achieves the peak strength (3.37 MPa), making it the optimal mix. At 100% replacement, a slight decrease (3.31 MPa) occurs, suggesting that full replacement may not be ideal. Overall, incorporating RFAs enhances concrete performance, but 75% replacement provides the best balance of strength and sustainability. Shown in **Fig. 8.**

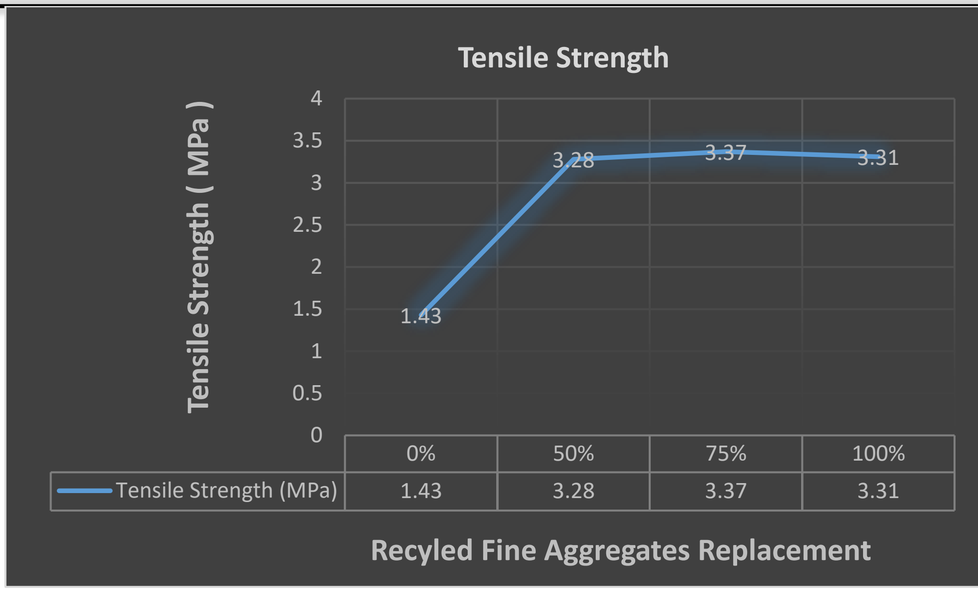

Fig. 8. Show the tensile strength against different proportion of RFAs

6. Discussion of Results

The results indicate that incorporating **Recycled Fine Aggregate (RFA)** and **Water-Reducing Admixtures (WRAs)** significantly influences the **compressive strength, tensile strength, and workability** of concrete. The **control mix (Normal Concrete)**, which consists of **100% sand and no WRAs**, exhibited the lowest mechanical properties, with a **compressive strength of 15.47 MPa**, a **tensile strength of 1.43 MPa**, and a **workability slump of 85 mm**. When **WRAs were added** to the normal concrete mix, both strength and workability improved, suggesting that WRAs enhance concrete's hydration process and overall performance.

As the **percentage of RFA increased**, compressive and tensile strength improved, with the highest compressive strength of **28.03 MPa** observed at **75% RFA replacement**. This suggests that **partial replacement of sand with RFA enhances the strength of concrete**, possibly due to better particle packing and increased cementitious properties of the recycled fines. The **tensile strength also peaked at 3.37 MPa for the 75% RFA mix**, indicating that the concrete's resistance to cracking improved with moderate RFA incorporation. Additionally, workability increased with RFA content, reaching a **maximum slump of 115 mm at 75% RFA**, which suggests that RFA and WRAs together improve the concrete's flowability.

However, at **100% RFA replacement**, a slight reduction in **compressive strength (26.35 MPa) and tensile strength (3.31 MPa)** was observed. This could be attributed to the increased water demand and porosity of fully recycled aggregates, which may negatively impact the concrete's overall bonding and density. Nevertheless, the **workability remained high at 110 mm**, indicating that complete sand replacement still maintains good flow properties but may slightly compromise strength.

7. Conclusion

Improved Mechanical Properties: The study highlights that replacing natural sand with Recycled Fine Aggregate (RFA) enhances the mechanical properties of concrete when combined with Water-Reducing Admixtures (WRAs).

Enhanced Workability: The use of RFA, in conjunction with WRAs, significantly improves the workability of concrete, making it easier to mix, place, and finish.

Optimal RFA Replacement Level: The most effective concrete mix was achieved at 75% RFA replacement. This mix provided the highest compressive strength of 28.03 MPa and tensile strength of 3.37 MPa, demonstrating superior structural performance.

Effect of Complete Replacement: A 100% replacement of natural sand with RFA resulted in a slight decline in strength. This suggests that a balanced combination of RFA and natural sand is necessary to achieve the best performance.

Sustainability & Eco-Friendly Construction: The study supports RFA as a viable and sustainable alternative to natural sand. It promotes eco-friendly concrete production, reducing reliance on natural resources.

Structural Integrity Maintained: Despite using recycled materials, the concrete maintained excellent structural integrity, reinforcing the potential of RFA in modern construction.

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