
**PERFORMANCE EVALUATION OF M20 GRADE CONCRETE
INCORPORATING FLY ASH AND RED SAND AS PARTIAL CEMENTITIOUS
REPLACEMENTS**

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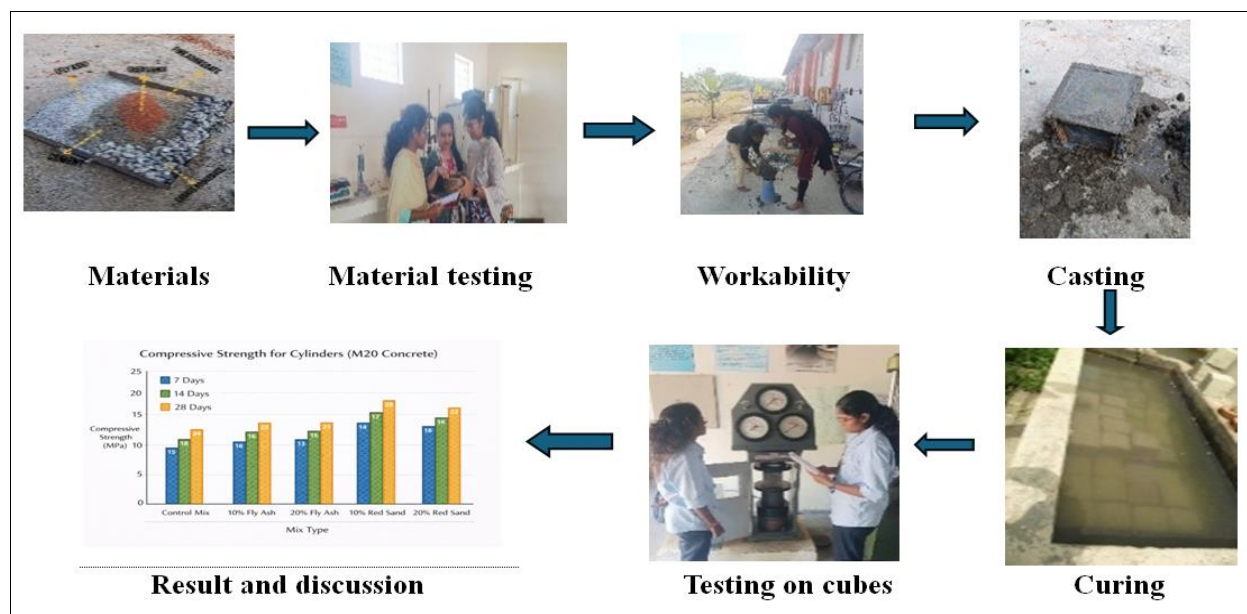
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ABSTRACT:

Concrete has the most globally used construction material, and the high consumption of cement leads to increased cost and environmental pollution due to carbon emissions. To address this issue, the partial replacement of cement with byproducts of industry cement compound materials is an effective solution. This study investigates the strength and durability properties of concrete by partially replacing cement with fly ash and red sand at proportions of 5%, 10%, 15%, and 20%. Compressive strength tests were conducted to evaluate strength variations, while durability aspects were assessed through water absorption and resistance to aggressive environments. The experimental results show that partial replacement of cement improves workability and improving life term strength and durability improvement to an optimum replacement level. Fly ash contributes to pozzolanic reactions, while red sand acts as a filler material, improving particle packing. This study concludes that using fly ash and red sand can produce sustainable and durable concrete.

KEYWORDS: Concrete, Fly Ash, Red Sand, Compressive Strength, Durability, Sustainable Construction.



Graphical Abstract

1. Introduction

Concrete is the most widely used construction material in civil engineering, valued for its strength, durability and adaptability across a wide range of structures. At the heart of this composite material lies cement the key binding agent that holds aggregates together enabling concrete to achieve the performance required for modern infrastructure. But its large-scale production leads to high energy consumption and significant carbon dioxide emissions, causing environmental concerns. To reduce the negative environmental impact and improve sustainability in construction, the use of supplementary cementitious materials has gained importance. Fly ash, a by-product of thermal power plants, possesses good pozzolanic properties that enhance the strength and durability of concrete. Red sand, obtained from soil, acts as a fine filler material and improves particle packing in concrete. Partial replacement of cement with fly ash and red sand can reduce cement consumption while maintaining or improving concrete performance. This experimental study focuses on evaluating the strength properties of concrete by partially replacing cement with fly ash and red sand at various replacement levels.

1.1 Need for the study

The use of alternative materials in concrete began to reduce cement consumption and environmental impact. Fly ash, a by-product of thermal power plants, has been used for many years due to its pozzolanic properties that improve strength and durability. Later, red sand was introduced as a filler material to enhance concrete performance. Recent studies combine

fly ash and red sand to produce economical and sustainable concrete. The increasing demand for cement has led to environmental pollution and depletion of natural resources. Large quantities of fly ash and red sand are available as waste materials, creating disposal problems. Utilizing these materials in concrete helps in waste management, cost reduction, and sustainable construction.

The scope of this study is to investigate the strength properties of concrete by partially replacing cement with fly ash and red sand. M20 grade concrete is used with replacement levels of 5%, 10%, 15%, and 20%. Concrete cube specimens of size 150 mm × 150 mm × 150 mm are cast and cured for 3, 7, 14, and 28 days. Compressive strength tests are conducted as per IS 456:2000 to evaluate performance and determine the optimum replacement level for sustainable concrete.

- To identify the optimum percentage of cement replacement for improved strength.
- To determine the compressive strength of concrete at different curing period ages of 3 days, 7 days, 14 days, and 28 days.
- To reduce cement consumption and predict environment in construction practices. To utilize industrial and natural waste materials effectively in concrete production.

1.2 Previous researcher's study

The integration of industrial byproducts and locally available materials into concrete production has become a primary focus for sustainable engineering. The research conducted by Reddy et al. (2023) highlights that replacing cement with fly ash in a range of 0% to 25% does not merely serve as a volume filler but actively enhances the long-term microstructure of the matrix. Their findings indicate that while early-age strength might be slightly lower due to the slower pozzolanic reaction of fly ash, the durability performance at advanced curing stages significantly exceeds that of conventional M20 or M25 mixes. This innovation methods were largely saved to the refinement of pore structures, which reduces permeability and enhances the resistance of the concrete to chemical attacks.

Building on these observations, the 2024 study published in IJRASET provides a more granular look at the mechanical thresholds of these replacements. By testing increments of 10%, 20%, and 30%, the researchers identified 20% as the critical tipping point for optimal performance. At this level, the synergy between the cement and the fly ash maximizes compressive, tensile, and flexural strengths. Beyond 30%, the reduction in primary binder content typically leads to a decline in mechanical integrity, suggesting that fly ash utilization must be carefully calibrated to maintain structural safety standards.

Furthermore, the research presented in IRJET (2023) introduces a dual-replacement strategy by incorporating red soil alongside fly ash. This study shifts the focus toward total resource optimization by addressing both the binder and the fine aggregate components. Using red soil as a little partial replacement in fine aggregates, combined with fly ash for cement, creates a complex interaction that affects the workability and density of the fresh concrete. The results demonstrate that while red soil can influence the water demand of the mix, the combined use of these materials supports the development of eco-friendly concrete that meets necessary strength requirements. Together, these studies validate that incorporating fly ash and red soil is a connecting pathway for reducing the usage of carbon footprint of the construction industry without compromising the longevity of the infrastructure.

2.MATERIALS AND METHODOLOGY

2.1 METHODOLOGY

The methodology involves preparing M20 concrete by partially replacing cement with fly ash and red sand at 0%, 5%, 10%, 15%, and 20% levels. Concrete cubes are cast and cured for 3, 7, 14, and 28 days. Compressive strength and durability tests are performed on these cubes, and the results are analyzed to evaluate the effect of varying percentages of fly ash and red sand on the strength and durability of concrete.

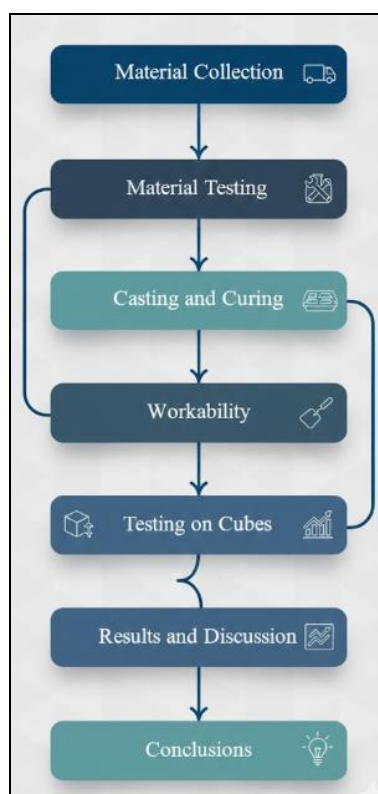


Fig.1: Proposed Methodology.

2.2 Materials Used

2.2.1 Cement:

Cement is the primary binding material in concrete that holds all the ingredients together. Ordinary Portland Cement (OPC) is commonly used due to its strength and durability. It reacts with water through hydration to form a hard matrix that binds aggregates. Cement provides structural integrity and contributes to the overall compressive strength of concrete. Its quality and proportion directly affect the performance and durability of the concrete mix.

2.2.2 Fly Ash:

Fly ash is a fine powder produced as a by-product of coal combustion in thermal power plants. It is a pozzolanic material that reacts with calcium hydroxide to form compounds with cementitious properties. When used as a partial replacement for cement, it improves the workability, strength, and durability of concrete. Fly ash also reduces permeability, enhances resistance to chemical attacks, and lowers the overall carbon footprint. Its use promotes sustainable and eco-friendly construction practices.

2.2.3 Red Sand:

Red sand is a naturally occurring fine aggregate used as a partial replacement for cement in concrete. It helps reduce the consumption of cement, thereby lowering the environmental impact. Red sand improves the sustainability of concrete while maintaining its strength and durability. It acts as a filler, enhancing the density and stability of the concrete mix. Its use contributes to eco-friendly construction practices without compromising structural performance.



Cement



Fly Ash



Red Sand



Portable Water



Coarse Aggregate



Fine Aggregate

Fig.2: Materials used in M 20 grade concrete.

2.2.4 Fine Aggregate:

Fine aggregate, usually natural sand, fills the voids between coarse aggregates in concrete. It improves the workability, strength, and finish of the concrete mix. Fine aggregate ensures uniform distribution of materials and reduces shrinkage cracks. It plays a key role in achieving the desired density and stability of concrete. Proper grading and quality of fine aggregate are essential for strong and durable concrete.

2.2.5 Coarse Aggregate:

Coarse aggregate, such as crushed stone or gravel, provides bulk and structural strength to concrete. It helps resist compressive forces and contributes to the overall load-bearing capacity. Coarse aggregate also reduces shrinkage and improves dimensional stability. The size, shape, and quality of coarse aggregate affect the workability and durability of concrete. Its proper selection is crucial for achieving strong and long-lasting concrete.

2.2.6 Water:

Water is an essential ingredient in concrete for the hydration of cement. It initiates the chemical reaction that allows cement to set and harden. The quantity and quality of water influence the strength, workability, and durability of concrete. Clean, potable water is preferred to avoid contamination that can weaken the mix. Proper curing with water ensures optimum strength development and longevity of concrete.

2.3 Mix Design and Cement Replacement:

The experimental framework for this study focuses on the M20 grade concrete mix, which is a standard requirement for many reinforced concrete structures. By systematically evaluating the mechanical and durability characteristics of this mix, the research aims to identify a sustainable balance between traditional binders and industrial or natural alternatives. The core methodology involves a controlled substitution where cement is incrementally replaced by equal portions of fly ash and red sand at levels of 0, 5, 10, 15, and 20 percent. This specific ratio ensures that for every gram of cement removed; a dual-component additive is introduced, maintaining the volumetric integrity of the binder paste while altering its chemical and physical properties.

Table 1: Fly ash + red soil replace cement equally percentages for concrete mixes.

Trial	Cement (kg)	Fly Ash (kg)	Red Soil (kg)	Fine Agg (kg)	Coarse Agg (kg)	Water (L)
T1 — 0%	1.29	0	0	2.33	4.33	0.645
T2 —	1.16	0.065	0.065	2.33	4.33	0.645

10%							
T3 20%	—	1.03	0.13	0.13	2.33	4.33	0.645
T4 30%	—	0.90	0.195	0.195	2.33	4.33	0.645
T5 40%	—	0.77	0.26	0.26	2.33	4.33	0.645

The primary control mix, designated as Trail 1, utilizes 1.29 kg of cement with no additives, serving as the benchmark for all subsequent comparisons. As the replacement levels increase, the cement content decreases to 0.774 kg in Trail 5. The addition of fly ash aims to utilize its pozzolanic reactivity, whereby it combines with calcium hydroxide, a by-product of cement hydration, to generate additional calcium silicate hydrate gel. Simultaneously, the inclusion of red sand, though often used as an aggregate, is tested here for its contribution to the matrix density and its potential to fill microscopic voids.

2.4 Impact on Hydration and Mechanical Strength

The hydration process is the fundamental chemical reaction that dictates the strength gain of concrete over time. In this experimental setup, the curing periods of 3, 7, 14, and 28 days are critical for capturing the varying rates of this reaction.

During the initial 3 to 7 days, the mixes with higher replacement levels may exhibit a slower rate of strength development because fly ash typically reacts more slowly than pure ordinary Portland cement. However, as the curing progresses toward 28 days, the pozzolanic reaction becomes more pronounced. The compressive strength tests performed on the cast cubes provide empirical evidence of how the combination of fly ash and red sand influences the load-bearing capacity.

Because the water-cement ratio and aggregate quantities are kept constant, any deviation in strength can be directly attributed to the binder substitution. The red sand contributes to a denser packing of the cementitious matrix, which can improve the overall compressive resistance by reducing the internal void ratio. This dense structure is essential for achieving the M20 target strength while utilizing a significantly lower volume of clinker-based cement.

2.5 Durability and Environmental Sustainability

Beyond mechanical strength, the durability of concrete determines its lifespan in harsh environments. The study incorporates durability testing to observe how the replacement materials resist environmental degradation, such as permeability and chemical ingress. Fly

ash is known to improve the workability of the fresh mix due to its spherical particle shape, which acts like ball bearings during the mixing process. This improved workability allows for better compaction, which in turn leads to a more durable finished product with fewer capillary pores.

From a sustainability perspective, the reduction of cement usage is a vital contribution to lowering the carbon footprint of construction. Cement production was the one of the major source of carbon dioxide emissions, and by removing up to 20 percent cement with fly ash a waste product from thermal power plants and red sand, this study provides a model for eco-friendly concrete. The results from the various trails help determine the optimum replacement percentage where the concrete remains durable and strong enough for structural applications while maximizing the use of alternative materials. This approach not only conserves natural resources but also offers a cost-effective solution for low-to-medium strength concrete requirements.

3. RESULTS AND DISCUSSION

The experimental study was carried out to evaluate the strength and durability characteristics of M20 grade concrete by partially replacing cement with Fly Ash and Red Sand. Concrete specimens were tested at curing ages of 7, 14, and 28 days, and the performance of the modified mixes was compared with that of the conventional control mix. The results showed a steady increase in compressive strength with curing age for all mixes due to the continuous hydration of cement and the progressive densification of the concrete structure. The control mix exhibited the highest compressive strength at all curing periods because it contained 100% cement, which hydrates rapidly and forms strong bonds within the concrete matrix. Mixes containing Fly Ash showed slightly lower strength at early ages. This reduction in early strength is mainly due to the slower pozzolanic reaction of Fly Ash, which requires time to react with calcium hydroxide released during cement hydration. As the curing period increased, Fly Ash mixes demonstrated significant strength gain. By 28 days, the strength values were close to the target strength of M20 concrete, indicating that Fly Ash contributes to long-term strength development by producing additional calcium silicate hydrate gel that fills internal voids and improves bonding.

Concrete containing Red Sand performed better at early ages compared to Fly Ash mixes. The reduction in compressive strength was minimal, especially at lower replacement levels. Red Sand helped improve particle packing and reduced voids in the concrete, resulting in better compaction and adequate strength. At 28 days, Red Sand mixes achieved strengths

nearly equal to the control mix, demonstrating that Red Sand can be effectively used as a partial replacement material without causing significant loss in strength.

Durability performance also improved with the use of these materials. Fly Ash mixes showed reduced water absorption due to the refinement of pore structure and the formation of additional binding products, making the concrete denser and less permeable. Red Sand mixes exhibited good compactness and bonding, which also helped in reducing water penetration. Lower permeability enhances resistance against environmental effects and increases the service life of concrete structures. Partial replacement of cement also reduced the heat of hydration, thereby minimizing thermal stresses and shrinkage cracks. This contributes to better long-term durability. The results indicate that moderate replacement levels provide a good balance between strength and durability. Excessive replacement may reduce early strength, but controlled use improves performance and sustainability.

3.1 Material Properties

The materials used in this project included cement, fine aggregate, coarse aggregate, water, and partial replacement materials like fly ash and red soil. Ordinary Portland Cement (OPC) of 43 grade was used. It showed good fineness, normal consistency, and proper setting time, meeting the requirements specified in IS 8112. The fine aggregate used was natural river sand conforming to Zone II as per IS 383, with proper gradation, specific gravity, and low water absorption. Crushed stone coarse aggregate of nominal maximum size 20 mm was used, having high crushing strength, acceptable impact value, and good abrasion resistance as per IS 2386. Clean potable water, free from impurities, was used for mixing and curing, in accordance with IS 456 recommendations. Fly ash used in the project conformed to IS 3812 and contributed to improved workability and long-term strength, while red soil was used as a partial replacement material after proper drying and sieving to ensure uniform particle size..

Table: 3 Material Properties.

Material and its characteristics	Cement	Fly ash	Red sand (%)	Fine aggregate (%)
Fineness	94%	360	2.55	2.65
Specific gravity	3.15	2.40	2.60	2.65
Density	1250	1000	1450	1500
Moisture content	0.5%	0.8%	4.5%	3%

The combined properties of these materials ensured adequate strength, durability, and performance of M20 grade concrete

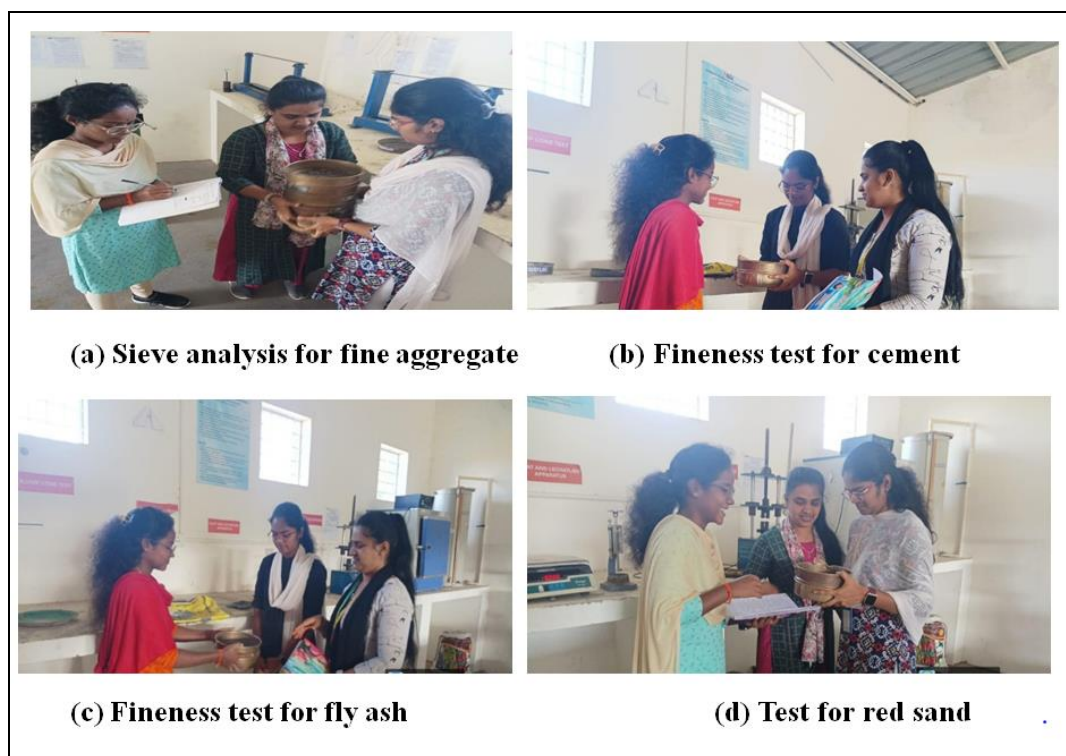


Fig.3: Checking Physical properties of materials.

3.2 Variations in Compressive Strength:

The results indicate that the concrete with 5% cement replacement exhibited a higher compressive strength compared to the control mix (0%) as well as mixes with higher replacement percentages.

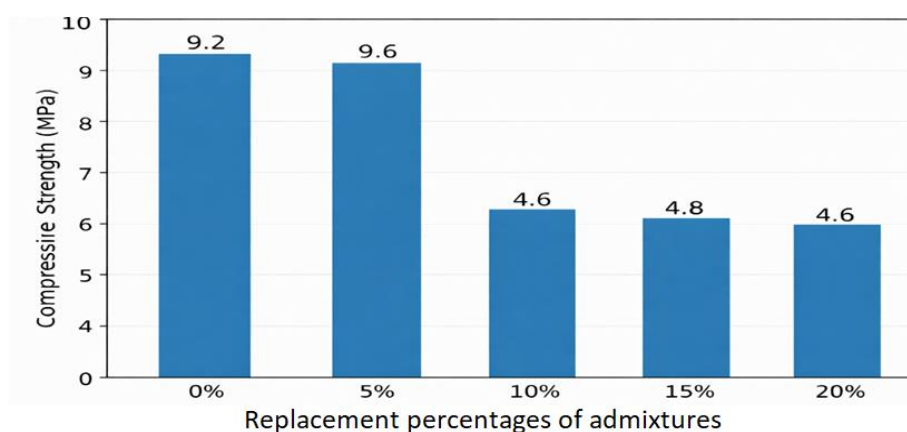


Fig.4: 3days Compressive strength vs % of replacement of admixture.

This improvement can be attributed to the filler effect and early pozzolanic activity of fly ash along with the fine particle packing provided by red soil, which enhanced the density of the cement matrix at low replacement levels. However, when the replacement level exceeded 5%,

a gradual reduction in compressive strength was observed at 3 days, mainly due to the reduced availability of cementitious material and the slower early-age strength development of fly ash. Hence, at early curing age of 3 days, 5% replacement of cement with fly ash and red soil proved to be the optimum percentage, providing better strength performance compared to higher replacement levels.

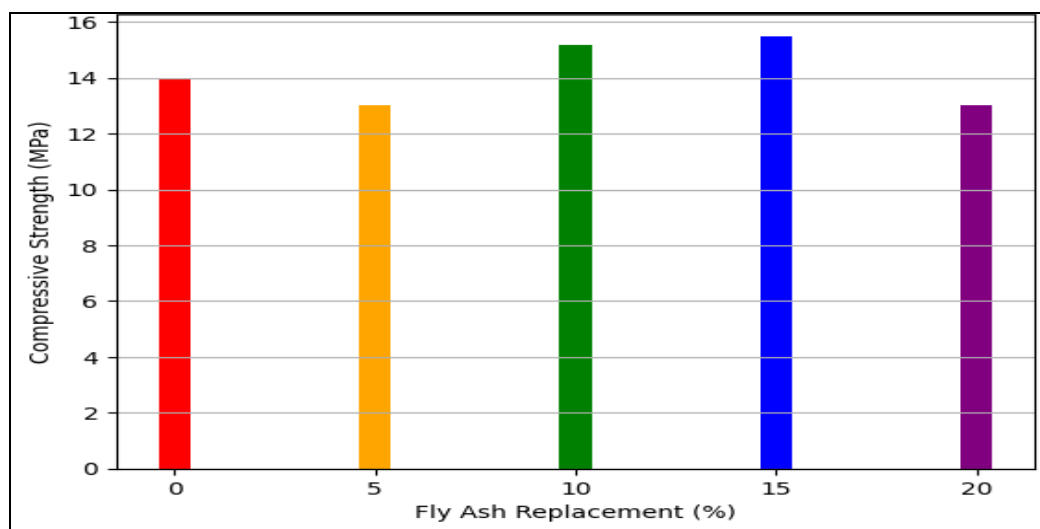


Fig.5: 7days Compressive strength vs % of replacement of admixture.

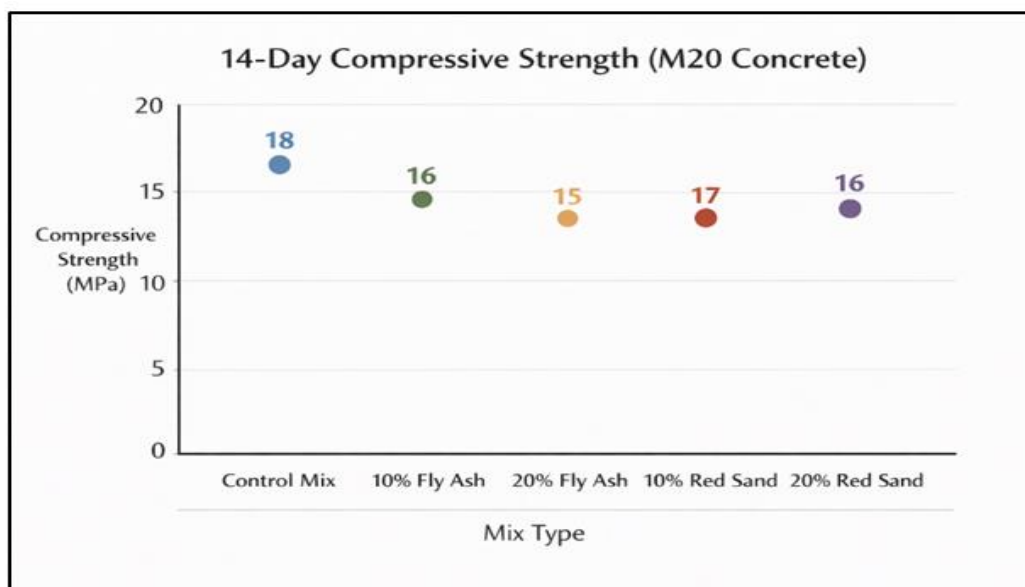
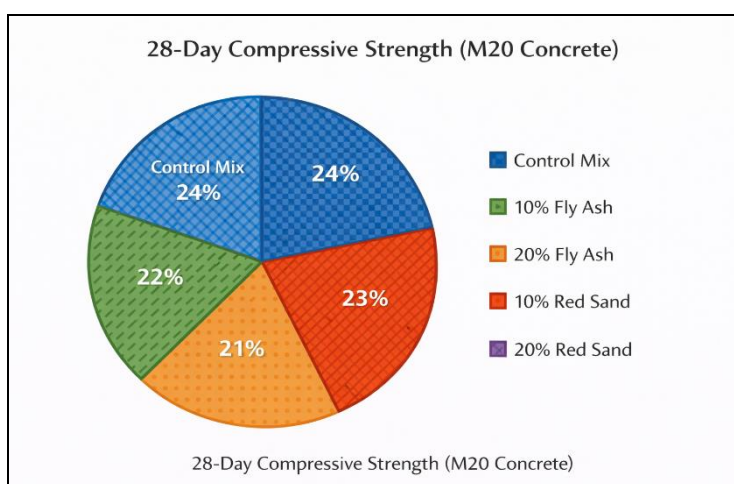


Fig.6: 14 days Compressive strength vs % of replacement of admixtures.

The 7-day compressive strength results for M20 grade concrete with partial replacement of cement by red sand and fly ash at 0%, 5%, 10%, 15% and 20% show a clear variation in early-age strength. The control mix (0% replacement) achieved about 14 MPa, which is

nearly 70% of the characteristic strength. At 5% replacement, the strength slightly reduced to about 13.11 MPa (65%). An improvement in strength was observed at 10% and 15% replacement, with values of approximately 15.22 MPa (76%) and 15.5 MPa (77.5%) respectively, indicating better particle packing and contribution of pozzolanic materials at moderate replacement levels. However, at 20% replacement, the strength decreased again to around 13 MPa (65%), due to reduced cement content and slower early hydration. Overall, the results indicate that 10–15% replacement levels provide better 7-day compressive strength, while higher replacement leads to strength reduction at early ages.



The 14-day compressive strength of M20 concrete for various mixes is represented using a dot/scatter plot. The control mix (100% cement) achieved the highest strength at 18 MPa. Partial replacement of cement with Fly Ash resulted in strengths of 16 MPa for 10% replacement and 15 MPa for 20% replacement. Similarly, replacing cement with Red Sand produced strengths of 17 MPa (10% replacement) and 16 MPa (20% replacement). The scatter plot clearly shows the relative performance of each mix, highlighting that while partial replacements slightly reduce early strength, all mixes still maintain sufficient compressive strength for general construction purposes.

Fig.7: Compressive strength of 28 days vs % of replacement of admixtures

The 28-day compressive strength of M20 concrete is illustrated in a pie chart for different mixes. The control mix (100% cement) achieved the highest strength at 24 MPa. Partial replacement with Fly Ash resulted in 22 MPa (10% replacement) and 21 MPa (20% replacement). Similarly, Red Sand replacements yielded 23 MPa (10% replacement) and 22 MPa (20% replacement). The pie chart visually represents the proportion of strength contributed by each mix, clearly showing that while partial replacements slightly reduce strength compared to the control mix, all mixes still achieve adequate compressive strength suitable for standard construction applications.

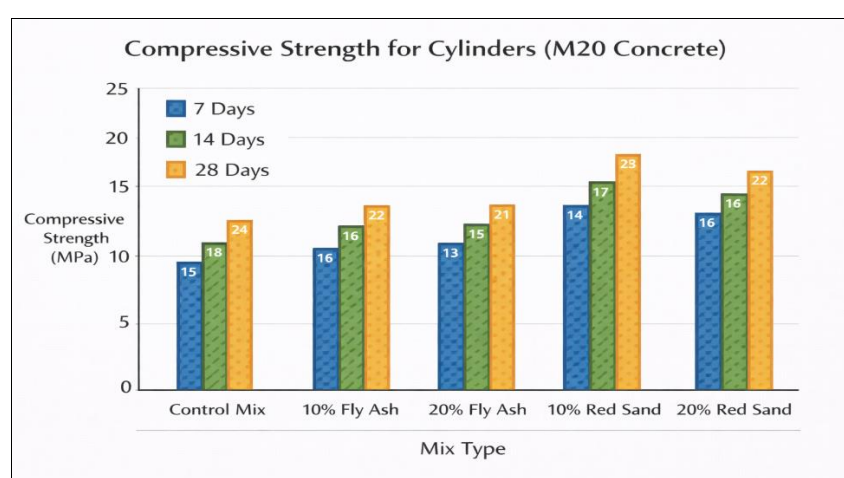


Fig.8: Compressive strength vs % of replacement of admixtures.

The graph shows the development of compressive strength of M20 concrete measured on standard 150×300 mm cylinders at 7, 14, and 28 days for different mixes. The control mix (100% cement) achieved strengths of 15 MPa at 7 days, 18 MPa at 14 days, and 24 MPa at 28 days. Partial replacement of cement with Fly Ash resulted in slightly lower strengths: 14 MPa and 16 MPa (10% Fly Ash), 13 MPa and 15 MPa (20% Fly Ash) at 7 and 14 days, reaching 22 MPa and 21 MPa at 28 days, respectively. Similarly, Red Sand replacements gave 14 MPa and 17 MPa (10% Red Sand), 13 MPa and 16 MPa (20% Red Sand) at 7 and 14 days, achieving 23 MPa and 22 MPa at 28 days. The graph clearly shows that compressive strength increases with curing age and that partial replacements slightly reduce early strength, but all mixes attain adequate 28-day strength for structural applications.

4. CONCLUSIONS

The study on the strength and durability of M20 grade concrete by partially replacing cement with Fly Ash and Red Sand demonstrates that sustainable materials can be effectively used

without significantly affecting the performance of concrete. The compressive strength results showed that all mixes gained strength with increase in curing age, confirming normal hydration and strength development behavior. Although replacement mixes showed slightly lower early-age strength compared to the control mix, the 28-day strength values were within the acceptable limits for M20 grade concrete.

Fly Ash replacement reduced early strength due to its slow pozzolanic reaction, but it improved long-term strength and durability by producing additional binding compounds that made the concrete denser and less permeable. Red Sand replacement showed better early strength performance and only a minor reduction in overall compressive strength. At lower replacement levels, especially around 10%, both Fly Ash and Red Sand mixes achieved strength values close to the control mix.

Durability characteristics such as reduced water absorption and improved resistance to permeability were observed in Fly Ash mixes due to refinement of pore structure. Red Sand also contributed to improved compactness and bonding. Partial replacement of cement lowered the heat of hydration, reducing the chances of shrinkage cracks and enhancing long-term performance.

Overall, the study concludes that partial replacement of cement with Fly Ash and Red Sand in M20 concrete is technically feasible, economical, and environmentally beneficial. A replacement level of about 10% provides the best balance between strength and durability while supporting sustainable construction practices.

5. SCOPE FOR FUTURE WORK

Building upon the established conclusions, the future scope of work focuses on shifting from laboratory-scale testing to long-term structural validation and industrial application. Since the 10% replacement level proved optimal for M20 grade concrete, subsequent investigations should evaluate the performance of this mix under more aggressive environmental conditions. This includes longitudinal studies on resistance to sulfate attack, chloride ion penetration, and carbonation depth over a period of 90 to 365 days to ensure the protection of embedded reinforcement.

Additionally, the research can be extended to higher grades of concrete, such as M30 or M40, to determine if the synergistic effects of fly ash and red sand remain consistent under higher binder intensities. Investigating the impact of chemical admixtures, like superplasticizers, could further optimize the water-cement ratio and enhance workability. Finally, a comprehensive life-cycle assessment and a comparative cost analysis would provide the

necessary data to encourage the adoption of these sustainable materials in large-scale commercial construction and governmental infrastructure projects.

Data Availability Statement

The experimental data that support the results of this study can be obtained from the corresponding author upon reasonable request.

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