STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Prin)
Volume 13, Special Issue 1, 2025
DOI [Journal]: 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

Parametric Study of Fiber-Reinforced Concrete With Partial Cement Substitution Using Fly Ash and Rice Husk Ash

Vivek Jayale[1,*], Dhiraj Agrawal[1], Abhay Patil[2], Ashwini Patil[3], Payal Jayale[1], Atul Kurzekar[1]

Abstract

This research aims to evaluate the impact of incorporating steel fibers [SF] and partially substituting cement with rice husk ash [RHA] and fly ash [FA] on the properties of concrete. SF were added in different volume fractions [0%, 0.25%, 0.5%, 0.75%, and 1.0%], combined with 10% RHA and 20% FA. Initially, the concrete mix contained 30% FA with no RHA, which was then adjusted to a mix of 15% FA and 15% RHA. The study explores how SF affects workability, compressive strength [CS], bending strength, splitting tensile strength [STS], resistance to acid and chloride attacks, and the overall cost when FA and RHA are used. Experimental findings show enhanced mechanical properties with the inclusion of FA, RHA, and SF. However, when the substitution surpassed 22.5%, the mechanical properties diminished. Furthermore, an increase in RHA content was found to reduce the concrete's workability.

Keywords: Rice husk ash, steel fibers, sustainable concrete, fiber reinforced concrete, cementitious materials

INTRODUCTION

The application of concrete in construction holds the second position in terms of usage, following only water. Nearly all components of concrete are sourced from natural resources [1]. The civil engineering field is actively striving to find substitutes for cement, exploring the potential of utilizing agro-industrial waste. Fiber Reinforced Concrete [FRC] is a composite material made of hydraulic cements, fine and coarse aggregates and a reinforcement fiber. FRC provides improved tensile strength, toughness, durability and ductility over traditional concretes. Reinforced Concrete: Speaking of beating climate change, adding fiber including steel, glass or synthetic to the mix can help to protect against cracking, hopefully enabling a larger load-bear on your universal map and enduring less wear-and-tear. Though a rise in need for sustainability and cost-effective solutions the alternative materials that has been experimented to replace it partially with conventional cement content based on Fly Ash and Rice Husk Ash [RHA] by Various researchers and Engineers, due to improving the properties of FRC provides economic faster farming revolution. In our reaesrch we have use Steel Fibre [SF] . SF were added in different volume fractions [0%, 0.25%, 0.5%, 0.75%, and 1.0%], combined with different percentage of FA and RHA. RHA, in its most general sense, is generated by burning rice husk under controlled conditions. Once it gets combusted to ash, this RHA harms the environment and damages the land and its surroundings when disposed of but RHA is silica-rich material whose industrial use has been really diverse. RHA is

*Author for Correspondence
Vivek Jayale

[1]Assitant Professor, Department of Civil Engineering, Yeshwantrao Chavan College of Engineering, Hingna Road, Wanadongri, Nagpur, Maharastra, India
[2]Professor, Department of Civil Engineering, Yeshwantrao Chavan College of Engineering, Hingna Road, Wanadongri, Nagpur, Maharastra, India
[3]Assitant Professor, Department of Civil Engineering, D Y Patil College of Engineering Akurdi, Pune, Maharastra, India

Received Date: June 24, 2024
Accepted Date: October 24, 2024
Published Date: 07 November, 2024

Citation: Vivek Jayale, Dhiraj Agrawal, Abhay Patil, Ashwini Patil, Payal Jayale, Atul Kurzekar. Parametric Study of Fiber-Reinforced Concrete with Partial Cement Substitution Using Fly Ash and Rice Husk Ash. Journal of Polymer & Composites. 2025; 13(Special Issue 1): S171–S180p.

widely used in construction as an additive cementitious material, that improves the properties of concrete with enhanced strength and durability while providing resistance to chemical attacks. It is further applied outside construction in ceramic, steel industries and applications of environment related to it, that opens up to more sustainable ventures [2,3][4]. One byproduct of burning pulverized coal in an industrial setting is FA. As a pozzolanic and cementitious component in concrete, FA has become increasingly popular in recent years[5]. It is a substance that can be added to blended cement or used as a stand-alone batch. Considering the production of these agricultural and industrial wastes, it is necessary to connect them with the rapidly growing construction industry which can be a viable solution for sustainable construction practice [6–12]. Both FA and RHA are waste materials, by using them in concrete decreases the volume of waste being delivered to landfills which is impact positively on environment from production view point. FA and RHA are known for providing better workability, reduce water demand, improve overall durability. Adding fibers in FRC also increases tensile strength and crack resistance, such that this combination is especially beneficial for high-performance construction applications. The use of FA and RHA as partial replacement in fiber reinforced concrete is a novel sustainability oriented method. While being helpful in addressing an environmental issues on one hand reduction in the usage of cementitious material, on the other it improves mechanical and durability properties of FRC. More research in this area will continue to benefit the improvement of concrete performance, which will be an effective means of construction for modern and ecological conservation[13,14].

An extensive experimental inquiry was undertaken to examine the impact of substituting a portion of cement with FA and RHA while incorporating SF into concrete[15,16]. The experimental procedure involved initially mixing 30% FA and 0% RHA in concrete, followed by a gradual adjustment where RHA increased by 2.5% and FA decreased by 2.5% until reaching a final proportion of 15% FA and 15% RHA.

METHODOLOGY

A total of 12 distinct concrete mixes were developed for this study to minimize cement usage and enhance strength through the use of steel fibers [SF]. Cement utilized was of grade 43 Ordinary Portland, conforming to the IS 269 and featuring a specific gravity of 3.15.[17]. The primary waste used for the fractional replacement of cement was FA, and the cement was substituted by FA from 15% to 30% with an increment of 2.5%. The specific gravity obtained for FA was 2.16. The RHA utilized is of specific gravity of 2.14 in this study.[18–20]. The amount of RHA incorporated in the concrete was from 0% to 15% with an increment of 2.5% by the weight of cement. The amount of SF included in the mix as a volumetric fraction from 0% to 1% with an incremental ratio of 0.25%. To enhance the strength of modified concrete, steel fibers with dimensions of 30 milimeter in length and 0.60 milimeter in diameter, resulting in an aspect ratio of 50, were used. The strength of concrete mixes incorporating RHA, FA, and SF was compared to that of conventional concrete. The chemical characteristics of cement, RHA, and FA were examined, as detailed in Table 1. The concrete mixtures were made by following the IS 10262[21]. The partial substitution of cement using FA and RHA along with the amalgamation of SF by volume of concrete is demonstrated in Table 2. The quantities of constituents required for each concrete mix are evaluated and shown in Table 3.

Table 1. Constituent Elements for Cementitious Materials.

Constituent elements	Cement %	FA %	RHA %
SiO_2	19.68	39	81.21
Al_2O_3	5.22	27	5.26
Fe_2O_3	3.73	5	6.28
CaO	61.86	18.50	6.53
MgO	2.54	4.52	---
SO_3	2.89	1.74	---
K_2O	0.9	0.8	---
LOI	0.96	3	4.98

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Table 2. Percentage of Cement, SF, FA, and RHA for 1m^3 Concrete.

Sr.N.	DesignMix ID	SF %	Cement %	FA %	RHA %
1	M0	0.00	100.00	0.00	0.00
2	M1	0.00	70.00	30.00	0.00
3	M2	0.00	70.00	27.50	2.50
4	M3	0.00	70.00	25.00	5.00
5	M4	0.00	70.00	22.50	7.50
6	M5	0.00	70.00	20.00	10.00
7	M6	0.00	70.00	17.50	12.50
8	M7	0.00	70.00	15.00	15.00
9	M8	0.25	70.00	20.00	10.00
10	M9	0.50	70.00	20.00	10.00
11	M10	0.75	70.00	20.00	10.00
12	M11	1.00	70.00	20.00	10.00

Table 3. Quantity of Constituents of Concrete Mixes are in [kg] for 1 cubic meter.

DesignMix ID	Cement	FA	RHA	SF	Sand	Coarse aggregate	Water
M0	443	0	0	0	647	1195	195
M1	310	133	0	0	647	1195	195
M2	310	122	11	0	647	1195	195
M3	310	111	22	0	647	1195	195
M4	310	100	33	0	647	1195	195
M5	310	89	44	0	647	1195	195
M6	310	78	55	0	647	1195	195
M7	310	66	66	0	647	1195	195
M8	310	89	44	19	647	1195	195
M9	310	89	44	39	647	1195	195
M10	310	89	44	59	647	1195	195
M11	310	89	44	79	647	1195	195

The concrete mixes were tested for their plastic properties and at the hardened stage. The slump test is the most frequently used technique for evaluating workability.

Slump test procedure: A cone-shaped mould [slump cone] is placed over flat surface. Fresh concrete is then placed in the cone in three layers, each layer tamped with a rod 25 times to consolidate.The cone is then raised straight up.We measure the difference in height of this concrete after we take its cone off [slump]. The tests were conducted according to the Indian standards [22–25]. Indian Standards used to determine properties of concrete IS1199 Part 2:2018 [26,27]. The evaluation of concrete mix workability hinges on the slump test, alongside investigating the impact of incorporating FA, RHA, and SF on concrete density. Density testing is used to find the mass per unit volume of concrete, which is vital for evaluating the quality and strength ASTM C138/ C137 M [28].

Density test procedure: Preapared concrete is added to a cylindrical mold in layers after mixing. Each layer is compacted with a rod to remove air voids. The mass of the sample is then weighed. The volume of the cylinder is given, therefore, the density [taking mass/volume] is determined.

One essential characteristic of concrete that shows how well it can withstand axial loads is its compressive strength. Compressive Strength

Test procedure: Concrete cubes and cylinders are casted and cured for a designated time.The specimens are then positioned in a compression testing machine, where a load is applied gradually until they fail[13,14,29,30]. The highest load at the point of failure is noted, and the compressive strength is calculated accordingly, IS 456:2000 [31].

The splitting tensile strength [STS] is a measure of the tensile strength of concrete, which is known to be weak in tension Splitting Tensile Strength

Test procedure: A cylindrical specimen is positioned horizontally in a compression testing machine. A load is applied across the diameter until the specimen fractures along the vertical axis[31].

The water absorption test evaluates how permeable and porous concrete is, which impacts its durability. Water Absorption

Test procedure: First, a we dried our casted concrete sample in an oven at a temperature of 100–110°C until it achieves a constant weight called dry weight. Next, these sample is submerged in water for 24 hours. After this period, the sample is weighed once more called wet weight British Standards 1881-122 2011 [32]. Water absorption is calculated as a percentage increase in weight.

The acid attack resistance test serves to assess the performance of concrete against chemical attack, mostly in acidic environments. Acid attack test procedure: Concrete specimens are cured for 28 days.

Afterwards, casted cubes immesered in a sulfuric acid [H2SO4] solution and maintaining the acid concentration for 56 days. The specimens are removed, and the loss in weight is determined. Also, the reduction in compressive strength after exposure is evaluated ASTM C 1898-20 [24].

Following this, the hardened properties of the modified concrete mixes are assessed over curing durations of seven, fourteen, twenty-eight, and ninety days to ascertain compressive strength. These results are subsequently compared with those of standard concrete, using IS 516:2021[33]. The bending and STS of concrete mixes are calculated under the IS 5816 1999 and IS 516:2021 [23,33] and the results are represented after twenty eight days of curing. The concrete's water absorption was assessed following British Standards 1881-122 2011 [32], Furthermore, the resistance to acid attack of the modified concrete was compared with that of the control concrete in accordance with ASTM C1898 − 20 [24]. Figure 1 shows the mixing, casting, slupm cone, and testing of concrete mixes repectively.

RESULTS AND DISCUSSIONS

Modified concrete mixes could potentially reduce structural dead loads, particularly beneficial for seismic-prone areas.

Workability and Density of Fresh condition Concrete

The concrete mixes workability is determined by referring to the IS 1199 Part 2:2018 [26,27] using the slump cone test. The modified concrete workability mixes is found to declined. This is due to incorporation of FA and RHA. The workability of control mis is found to be 96 mm. while the least workability is obtained for the mix M7 as 65 mm. This mix is the amalgamation of 15% each of FA and RHA as a fractional substitution of cement. The insertion of Sf from 0% to 1% by volume with an increment of 0.25% showed a decrement in the rate of reduction of workability[11,12]. The mixes M8, M9, M10, and M11 showed a slump value of around 75 mm at 20% FA and 10% RHA with varying percentages of SF. The decrease in the slump value for concrete mixes with FA, RHA, and SF is 23.9%. the results of workability are shown in Figure 2.

The density of fresh concrete is assessed by following IS 1199 [34] . As the density of FA used in this experiment is 2.33 and the density of RHA is 2.19, so the reduction in the densities of concrete mixes is observed when compared to the control concrete. The minimum density is obtained for the mix M7 with a reduction of 3%. The impact of including FA and RHA in concrete resulted in minimal density reduction, whereas the addition of SF led to increased density. Specifically, mix M11 experienced a density increase of 2.5%. Mix M8 demonstrated a density comparable to the control mix. The density results for the concrete mixes are illustrated in Figure 2.

Journal of Polymer & Composites
Volume 13, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Figure 1. [a] Mixing, [b] Casting, [c] Workability, [d, e, f] concrete's mechanical properties.

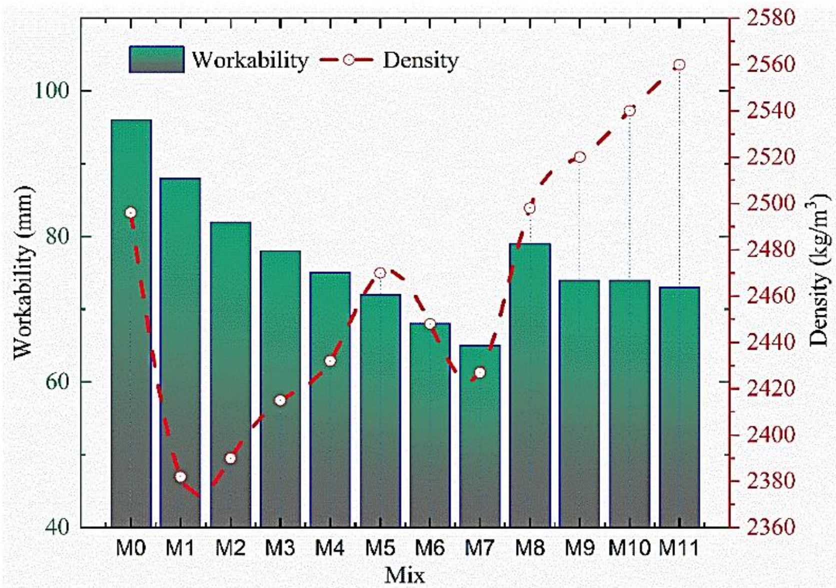

Figure 2. Workability and density of concrete mixes

Strength in Compression of Concrete

Compressive strength [CS] evaluation across different concrete blends indicated a strengthening trend with higher FA content, substituting a portion of cement. Strength improved with up to a 10% replacement of RHA. However, surpassing this threshold with further RHA substitution led to a decrease in compressive strength. Notably, mix M5 showcased a CS nearly on par with the control concrete. Conversely, mixes M6 and M7 displayed the lowest strengths at 28 days, measuring 31.2 MPa and 30.2 MPa, respectively. Figure 3 illustrates that an increase SF percentage correlates with enhanced compressive strength. Mixes M2, M3, M4, and M5 demonstrated compressive strengths comparable to the control concrete. Notably, the CS of mix M5 measured at 35 MPa surpassed that of the control concrete. With 20% FA and 10% RHA, mix M5 represents the optimal replacement of cement with RHA up to 10%, as further increases in RHA content led to a decline in strength. Following the determination of the optimal FA and RHA composition, the influence of SF on concrete strength was assessed by incorporating it into the mix containing 20% FA and 10% RHA.

Bending and Spliting Strength in Tension

The flexural or bending strength is determined as per to IS 516 standards.[22]. Bending strength of modified mixes is eavaluted against that of the control concrete using concrete specimens shaped as 10 x 10 x 50 cm rectangular beams. [31,35,36]. The bending strength of concrete mixtures increases as the FA and RHA content rises, peaking with a 10% addition of RHA. However, additional increases in RHA content lead to a decrease in bending strength. This is due to its high reactivity and fine particle size, the optimal replacement levels for RHA are usually lower than FA, around 10%. Beyond this, too much RHA may increase water demand and affect workability, which resulted negatively impact flexural strength to particularly, mix M7 exhibits the lowest bending strength at 4.8 MPa, representing a 22.3% decrease compared to the control concrete. Mixture M6 achieves a bending strength of 5.05 MPa, while mix M5 surpasses the strength of the control mix of concrete. Incorporating SF in the modified concrete further enhances bending strength, with mix M11 displaying the maximum bending strength, indicating an increase of 33.8%. The most effective substitution of FA and RHA occurs at 20% and 10%, correspondingly, as partial replacements for cement. Figure 4 represents a breakdown of the bending strength of different concrete mixtures. The STS of these mixes is assessed according to Indian Standards following 28 days of curing. [22,23].STS conducted on cylindrical specimen. It's observed that an increase in FA and RHA content which results in declined in STS. The STS of the control concrete measures 4.4 MPa. Mixes M6 and M7 exhibit strengths of 2.26 MPa and 2.1 MPa respectively. Introduction of SF in the modified concrete mixes enhances their strength. Figure 4 illustrates the variance in splitting strengths of the concrete mixes under tension. The findings indicate that modified concrete mixes lacking SF tend to experience a reduction in STS, while those incorporating SF demonstrate improved strength.

WaterAbsorption and Acid Attack Test

Rreferring to BS 1881[32] concrete mixes water absorption of is examined. Following the procedure, cylindrical specimens measuring 7.5 cm in height and diameter are subjected to water immersion for 30 minutes, 60 minutes, and 120 minutes. It is noted that water absorption increases with higher FA and RHA content across all concrete specimens. RHA fine particles have a tendency to absorb more water. If there isn't enough water in the mix, the cementitious materials may not hydrate completely, resulting in micro-pores and voids within the matrix. These voids can lead to increased water absorption. Incorporating SF in modified mixes results in reduced water absorption, although their absorption rates remain higher compared to conventional concrete mixes. Mix M7 exhibits the highest water absorption at 4.17%, while for SF-containing mixes, the maximum absorption is noted as 3.72% for mix M8. Figure 5 illustrates the varying water absorption levels across all mixes of concrete.

Accordance with ASTM standards acid attack on concrete mixes are evaluated , utilizing a sulfuric acid [H_2SO_4] solution and maintaining the acid concentration for 56 days. This test entails measuring the percentage weight loss and CS loss of concrete cubes. The findings, depicted in Figure 6, reveal that higher FA and RHA content correspond to increased CS loss. Notably, mix M7 demonstrates the highest percentage loss in compressive strength, indicating that excessive RHA content contributes to greater strength reduction following acid exposure. Crack propagation in the modified concrete mixes due to reduction in strength. Detailed results of the acid attack demonstrate that incorporating SF in concrete can mitigate the percentage loss. Mix M7 records the maximum loss at 17.9%, while mix M11, comprising 20% FA, 10% RHA, and 1% SF, exhibits the minimum loss. The maximum percentage weight loss of concrete cubes is observed at 2.86% for mix M7.

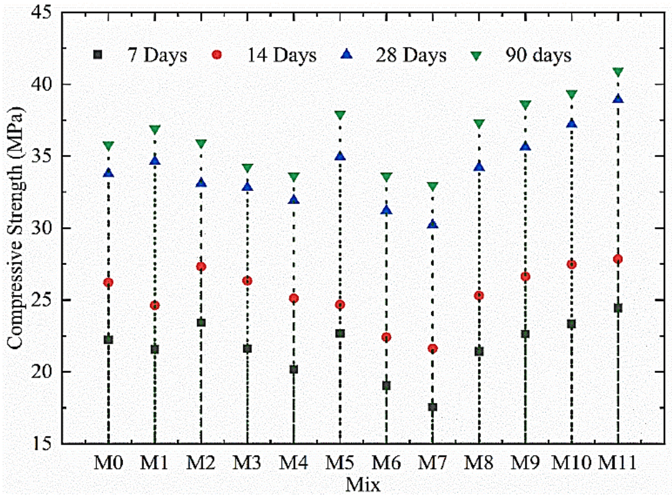

Figure 3. Changes in CS across concrete mixtures incorporating FA, RHA, and SF.

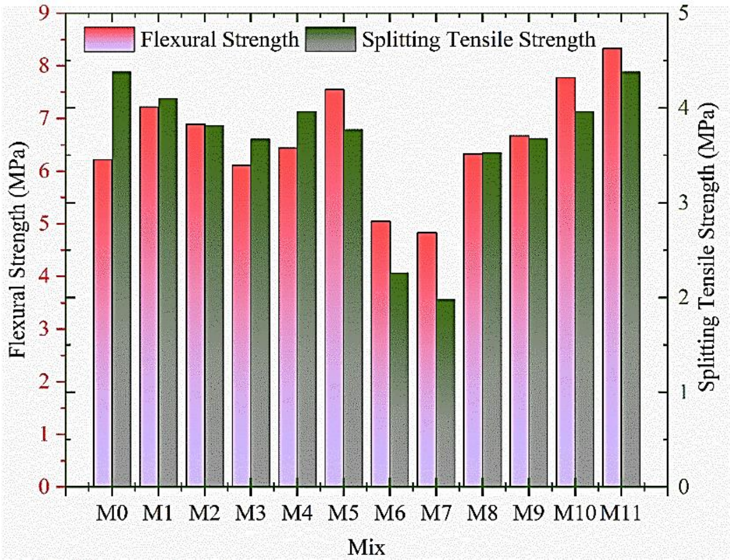

Figure 4. Variation in splitting and flexural strength concrete mixtures.

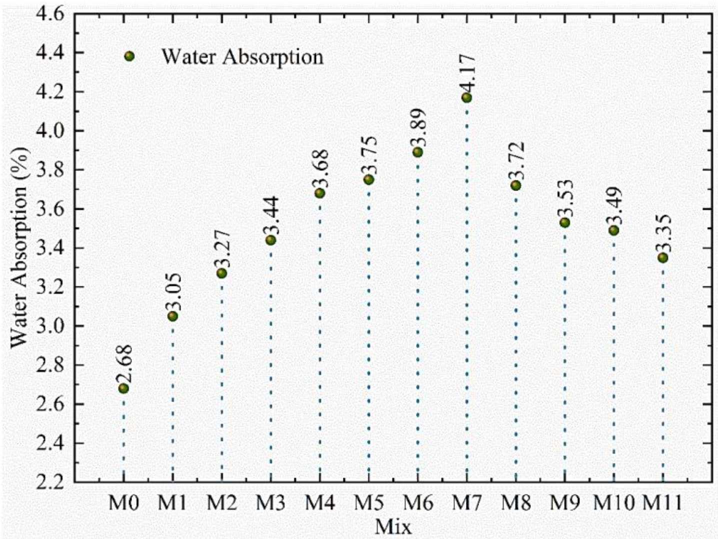

Figure 5. Variation in waterabsorption for all concrete mixes.

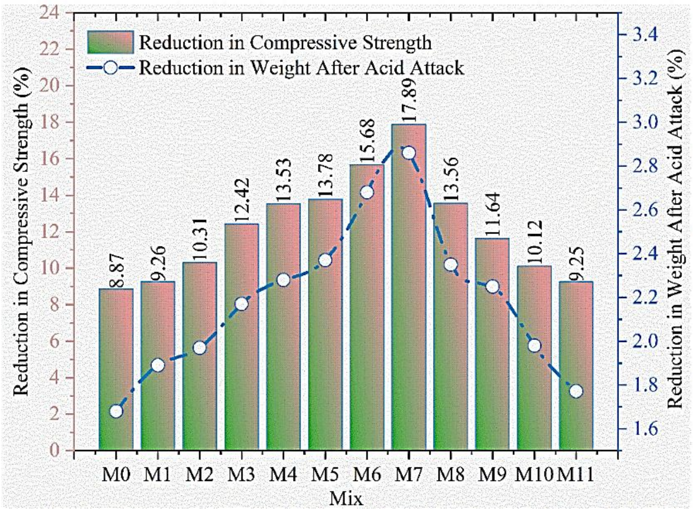

Figure 6. Percentage reduction in CS for all concrete mixes.

CONCLUSIONS

After conducting various tests on concrete, as well as durability assessments, the following conclusions emerge:

- With higher FA and RHA content workability of concrete decreases, although mix M5 yields satisfactory results. The addition of SF mitigates this decrease in workability to some extent.
- The impact of FA and RHA on concrete is minimal up to a 20% substitution of FA and a 10% replacement of RHA. Further increases in both materials lead to a decline in concrete performance. Incorporating SF proves advantageous for enhancing strength in modified mixes.
- FA and RHA inclusion result in decreased flexural and splitting tensile strengths of modified concrete mixes. Optimal results, akin to the control concrete, are achieved at maximum FA of 20% and RHA of 10%. Incorporating SF enhances both bending and STS.
- As the content of FA and RHA rises, water absorption also increases in all modified concrete mixes. However, mixes M5, M8, M9, M10, and M11 remain within acceptable limits, similar to the control concrete.
- Acid attack resistance reveals increased percentage loss in compressive strengths for modified mixes. SF incorporation into concrete can mitigate this loss in CS due to acid attack.The experimental results of this study concluded that the incorporation of FA and RHA up to 20% and 10% respectively can be the viable solution to make the construction activity sustainable. The insertion of SF in this altered mix can impart more strength to the concrete than the control concrete.

REFERENCES

1. Agrawal D, Waghe U, Ansari K, Amran M, Gamil Y, Alluqmani AE, et al. Optimization of eco-friendly concrete with recycled coarse aggregates and rubber particles as sustainable industrial byproducts for construction practices. Heliyon. 2024;10[4]:e25923.
2. Chetan D, Aravindan A. An experimental investigation on strength characteristics by partial replacement of rice husk ash and Robo sand in concrete. Mater Today Proc. 2020;33[xxxx]:502–7.
3. Mosaberpanah MA, Umar SA. Utilizing Rice Husk Ash as Supplement to Cementitious Materials on Performance of Ultra High Performance Concrete: – A review. Materials Today Sustainability. 2020;7–8:100030.
4. Songpiriyakij S, Kubprasit T, Jaturapitakkul C, Chindaprasirt P. Compressive strength and degree of reaction of biomass- and fly ash-based geopolymer. Constr Build Mater. 2010;24[3]:236–40.
5. Qureshi LA, Ali B, Ali A. Combined effects of supplementary cementitious materials [silica fume, GGBS, fly ash and rice husk ash] and steel fiber on the hardened properties of recycled aggregate concrete. Constr Build Mater. 2020;263[2020]:120636.

6. Mehta A, Siddique R. An overview of geopolymers derived from industrial by-products. Constr Build Mater. 2016;127:183–98.
7. Kavyateja BV, Reddy PN, Kumar A. Properties of self-compacting concrete modified with ultrafine slag. Research on Engineering Structures and Materials. 2022;8[2]:371–84.
8. Agrawal D, Waghe UP, Raut SP. Performance Evaluation of Rubberized Concrete with the Use of Steel Fibers. In © Springer Nature Singapore Pte Ltd. 2021; 2021. p. 709–17.
9. Abbaszadeh S, Wan Alwi SR, Ghasemi N, Muhamad ID. Removal of Pb[II] from aqueous solution using papaya peel. Regional Symposium on Chemical Engineering [RSCE] and Symposium of Malaysian Chemical Engineering [SOMChE]. 2014;1[October]:1–9.
10. Patil AR, Sathe SB. Feasibility of sustainable construction materials for concrete paving blocks: A review on waste foundry sand and other materials. Mater Today Proc. 2021;43:1552–61.
11. Patil A, Jayale V, Arunachalam KP, Ansari K, Avudaiappan S, Agrawal D, et al. Performance Analysis of Self-Compacting Concrete with Use of Artificial Aggregate and Partial Replacement of Cement by Fly Ash. Buildings [Internet]. 2024 Jan 6;14[1]:143. Available from: https://www.mdpi.com/2075-5309/14/1/143
12. Patil A, Kumar Dwivedi A. Mechanical strength and durability performance of sea water concrete incorporating supplementary cementitious materials in different curing conditions. Mater Today Proc. 2022;65:969–74.
13. Patil A, Kumar Dwivedi A. Mechanical strength and durability performance of sea water concrete incorporating supplementary cementitious materials in different curing conditions. Mater Today Proc. 2022;65:969–74.
14. Agrawal D, Waghe UP, Goel MD, Bagde A. Effect of Micro-silica and Crumb Rubber on Mechanical Properties of Concrete. Engineering Access [Internet]. 2024 Jun 26;10[2]:189–96. Available from: https://ph02.tci-thaijo.org/index.php/mijet/article/view/252912
15. Khaloo A, Raisi EM, Hosseini P, Tahsiri H. Mechanical performance of self-compacting concrete reinforced with steel fibers. Constr Build Mater. 2014;51.
16. Ponikiewski T, Gołaszewski J. The influence of high-calcium fly ash on the properties of fresh and hardened self-compacting concrete and high performance self-compacting concrete. J Clean Prod. 2014;72.
17. IS 269. Ordinary Portland Cement Specification. IS 269-2015, New Delhi, India. 2015;Sixth Revi[December]:01–14.
18. Sandhu RK, Siddique R. Influence of rice husk ash [RHA] on the properties of self-compacting concrete: A review. Vol. 153, Construction and Building Materials. 2017.
19. Zeyad AM. Effect of fibers types on fresh properties and flexural toughness of self-compacting concrete. Journal of Materials Research and Technology. 2020;9[3].
20. Muhammad A, Thienel KC, Sposito R. Suitability of blending rice husk ash and calcined clay for the production of self-compacting concrete: A review. Vol. 14, Materials. 2021.
21. IS 10262. Concrete Mix Proportioning Guidelines. IS 10262-2019, New Delhi, India. 2019;
22. IS 516. Hardened concrete - Methods of test. IS 516-2021, New Delhi, India. 2021;54[August]:1–20.
23. IS 5816. Specification for splitting tensile strength of concrete -Method of Test. IS 5816-1999, New Delhi, India. 1999;1–8.
24. ASTM C1898 20. Standard Test Methods for Determining the Chemical Resistance of Concrete Products to Acid Attack. ASTM International. 2020;[Stage II]:9–10.
25. ASTM: C138/C138M-13. Standard Test Method for Density [Unit Weight], Yield, and Air Content [Gravimetric]. ASTM International. 2013;i:23–6.
26. IS 1199. Methods of sampling and analysis of concrete. IS 1199. 1959;1–49.
27. IS 1199 Part 2 2018. Fresh Concrete Methods of Sampling, Testing and Analysis Part 2 . 2018.
28. ASTM C 138. Standard Test Method for Density.
29. Mohamed HA. Effect of fly ash and silica fume on compressive strength of self-compacting concrete under different curing conditions. Ain Shams Engineering Journal. 2011;2[2]:79–86.
30. Hamza B, Said K, Belkacem M. The influence of recycled steel fibers on self-compacting concrete performance. In: IOP Conference Series: Materials Science and Engineering. 2018.

31. Bureau of Indian Standards IS-456:2000. Plain and Reinforced Concrete- Code of Practice. 2000 [cited 2023 Aug 2]; Available from: www.standardsbis.in
32. BS 1881-122. BSI Standards Publication Testing concrete Part 122 : Method for determination of water absorption. BSI Standards. 2011;1–8.
33. Bureau of Indian Standards IS-516:2021. Hardened Concrete- Method of Test. 2021 [cited 2023 Aug 2]; Available from: www.standardsbis.in
34. IS 1199-3. Fresh Concrete-Methods of Sampling, Testing and Analysis Part 3 Determination of Density of Fresh Concrete [First Revision] [Internet]. 2018. Available from: www.standardsbis.in
35. Akinpelu MA, Odeyemi SO, Olafusi OS, Muhammed FZ. Evaluation of splitting tensile and compressive strength relationship of self-compacting concrete. Journal of King Saud University - Engineering Sciences. 2019;31[1].
36. Dhiyaneshwaran S, Ramanathan P, Baskar I, Venkatasubramani R. Study on durability characteristics of self-compacting concrete with fly ash. Jordan Journal of Civil Engineering. 2013;7[3].

