International Journal of Recent Research and Review, Vol. XIX, Issue 3, September 2026

ISSN 2277 – 8322

EXPERIMENTAL INVESTIGATION OF SUSTAINABLE CONCRETE INCORPORATING SILICA FUME, RICE HUSK ASH AND IRON SLAG AS PARTIAL CEMENT REPLACEMENTS

Vaibhav Raj Sharma

M.Tech Student, Department of Civil Engineering, Arya College of Engineering, Jaipur
vaibhavrajsharma2001@gmail.com

Anil Kumar Sharma

Assistant Professor, Department of Civil Engineering, Arya College of Engineering, Jaipur
anilsharma2701@gmail.com

Abstract: Concrete is one of the most widely used construction materials worldwide, but the extensive use of cement contributes significantly to environmental pollution and resource consumption. This study investigates the performance of sustainable concrete by incorporating silica fume, rice husk ash, and iron slag as partial replacements for cement. These materials are industrial and agricultural waste products containing significant pozzolanic and silica-rich components, making them suitable for use in sustainable concrete production. The experimental study evaluates the effect of these mineral admixtures on the compressive and flexural strength of hardened concrete. Different replacement levels are considered to assess their influence on the strength and overall performance of concrete. The results are comparatively analyzed to identify suitable combinations of silica fume, rice husk ash, and iron slag for producing sustainable and high-performance concrete. The study demonstrates the potential of these waste-based materials to reduce cement consumption while maintaining the required mechanical properties of concrete.

Keywords: Silica Fume; Rice Husk Ash; Iron Slag; Sustainable Concrete; Supplementary Cementitious Materials; Partial Cement Replacement; Compressive Strength; Flexural Strength; Split Tensile Strength; Sustainable Construction.

I. Introduction

Concrete is one of the most widely used construction materials worldwide and plays a fundamental role in residential, commercial, industrial, and infrastructure development. Its extensive use is primarily attributed to its high compressive strength, durability, versatility, availability of raw materials, and relatively low cost. Conventional concrete generally consists of cement, fine aggregate, coarse aggregate, water, and, where required, chemical or mineral admixtures. Among these constituents, cement acts as the primary binding material and is responsible for developing the strength and cohesion of the concrete matrix. However, the large-scale production and consumption of Portland cement have raised significant environmental concerns because cement manufacturing requires substantial energy and is associated with considerable carbon dioxide emissions. Therefore, reducing the consumption of conventional cement through the incorporation of suitable alternative materials has become an important approach toward developing sustainable concrete. SCMs and mineral admixtures have attracted considerable attention as partial replacements for cement because of their potential to reduce cement consumption while maintaining or improving the engineering performance of concrete. Materials containing high amounts of reactive or amorphous silica can participate in pozzolanic reactions with calcium hydroxide released during cement hydration. These reactions can promote the formation of additional calcium silicate hydrate (C-S-H) gel, which is primarily responsible for the strength and densification of the cementitious matrix. In addition to their chemical contribution, finely divided mineral materials can improve particle packing and reduce the volume and connectivity of pores within the concrete matrix. Consequently, the appropriate incorporation of such materials can improve mechanical properties and contribute to enhanced durability.

Silica fume (SF), rice husk ash (RHA), and iron slag (IS) are promising materials for partially replacing conventional cement. Silica fume, a fine silica-rich by-product of silicon and ferrosilicon production, enhances pozzolanic activity, matrix densification, and concrete strength. Rice husk ash, obtained from the controlled burning of rice husk, contains reactive silica and can contribute to additional C-S-H formation and pore refinement. Its performance depends on factors such as burning conditions, fineness, and replacement level. Iron slag, an industrial

ISSN 2277 – 8322

by-product of iron and steel production, can be processed and used as a supplementary cementitious material, contributing to improved concrete properties while promoting industrial waste utilization and reducing cement consumption.

The utilization of agricultural and industrial wastes such as rice husk ash and iron slag in concrete can reduce waste-disposal problems and decrease dependence on conventional cement, thereby supporting resource conservation and sustainable construction. The mechanical performance of such concrete can be evaluated through compressive, flexural, and split tensile strength tests. In this study, silica fume, rice husk ash, and iron slag were used individually and in combination as partial cement replacements, and their effects were evaluated at 7, 14, and 28 days. The objective was to identify suitable replacement levels that provide satisfactory mechanical performance while promoting waste utilization and reducing the environmental impact of cement-based concrete.

II. TEST OF CONCRETE

The mechanical properties of concrete are commonly evaluated through standardized laboratory tests. The compressive strength and flexural strength tests are among the most important tests used to assess the structural performance of concrete. The specimens should be prepared, cured, and tested in accordance with the relevant Indian Standard specifications to ensure reliable and reproducible results.

A. Compressive Strength of Concrete

The compressive strength test was conducted to determine the maximum load-bearing capacity of concrete specimens under compression. Standard cube specimens of 150 mm × 150 mm × 150 mm were prepared using the designed proportions of cement, fine aggregate, coarse aggregate, water, and mineral admixtures. The constituents were accurately measured, thoroughly mixed, and the fresh concrete was checked for workability in accordance with the relevant provisions of IS 1199. The concrete was placed into moulds in layers and properly compacted to eliminate entrapped air. After casting, the specimens were stored under controlled conditions, demoulded, and cured in water until the required testing ages of 7, 14, and 28 days. Before testing, the specimens were cleaned, measured, and centrally positioned in the compression testing machine. The load was applied continuously and uniformly in accordance with the applicable requirements of IS 516 until failure occurred. The maximum load at failure was recorded, and the compressive strength was calculated from the failure load and loaded cross-sectional area. The observed mode of failure was also noted.

B. Flexural Strength

The flexural strength test was conducted to determine the resistance of concrete to bending in accordance with IS 516. Standard beam specimens were prepared using the specified concrete mix and placed in moulds in approximately three layers, with each layer properly compacted to ensure uniformity and avoid segregation. After casting, the specimens were demoulded and cured in water until the required testing age. Before testing, the specimens were removed from the curing tank and placed centrally on the supports of the flexural testing machine. The supporting and loading rollers were cleaned and properly aligned. The load was then applied continuously and uniformly without shock until failure occurred. The maximum load and crack location were recorded, and the flexural strength (modulus of rupture) was calculated using the appropriate equation specified in IS 516.

Fig 1: Flexural Strength Test

C. Split Tensile Test

The split tensile strength test was conducted to determine the indirect tensile strength of concrete in accordance with IS 5816:1999. Cylindrical specimens were removed from water curing after the specified testing period, such as 7 and 28 days, and their dimensions were measured. Diametrical lines were marked on both ends of the specimen to ensure proper alignment. The cylinder was positioned centrally between the loading platens with suitable packing strips placed along its diameter. A continuous and uniform compressive load was applied without shock until the specimen failed by splitting along the diametral plane. The maximum failure load was recorded, and the split tensile strength was calculated using the appropriate equation specified in IS

5816:1999. The observed crack pattern and mode of failure were also noted.

Fig 2: Split Tensile Test

III. MIX FORMULATION WITH CONCRETE MIX OF M-40 GRADE

Portion ratio of mix (1:1:2:0.35) as Cement: Sand: Aggregate

Table 1: Mix of concrete with Silica Fume

% Replacement of Silica Fume	Cement	Sand	Aggregate
0%	100%	100 %	100%
7%	93%	100 %	100%
14%	86%	100 %	100%
21%	79%	100 %	100%
28%	72%	100 %	100%

Table 2: Mix of concrete with Rice Husk Ash

% Replacement of RHA	Cement (%)	Sand (%)	Aggregate (%)
0	100	100	100
7	93	100	100
14	86	100	100
21	79	100	100
28	72	100	100

Table 3: Mix of concrete with Iron Slag

% Replacement of Iron Slag	Cement (%)	Sand (%)	Aggregate (%)
0	100	100	100
7	93	100	100
14	86	100	100
21	79	100	100
28	72	100	100

Table 4: Mix of concrete with All Material Combine

% Replacement of (SF+RHA+IS)	Cement (%)	Sand (%)	Aggregate (%)
0	100	100	100
7	93	100	100

14	86	100	100
21	79	100	100
28	72	100	100

Table 5: Property of Risk Husk

Property	**Values**
Silica (SiO_2)	87.20%
Alumina (Al_2O_3)	0.15%
Ferric oxide (Fe_2O_3)	0.16%
Calcium oxide (CaO)	0.55%
Magnesium oxide (MgO)	0.35%
Sulfer trioxide (SO_3)	0.24%
Carbon (C)	5.91%
Loss on ignition (LOI)	5.44%
Fineness passing 45 micron	96%
Mineralogy	None Crystalline
Shape	Irregular

IV. PROPERTIES OF MATERIAL

Table 6: Properties of Fly Ash and Silica Fume

Property	**Fly Ash**	**Silica Fume**
Physical form	Fine powder	Very fine powder
Colour	Grey to dark grey	Grey to light grey
Specific gravity	2.10–2.60	2.10–2.30
Bulk density	800–1,200 kg/m³	300–700 kg/m³
Particle size	1–100 µm	0.1–0.5 µm
Specific surface area	300–600 m²/kg	15,000–30,000 m²/kg
Silica (SiO_2)	40–60%	85–98%
Alumina (Al_2O_3)	20–35%	0.5–2.0%
Ferric oxide (Fe_2O_3)	3–15%	0.5–2.0%
Calcium oxide (CaO)	1–15%	0.1–1.0%
Magnesium oxide (MgO)	1–5%	0.5–2.0%
Loss on ignition (LOI)	< 5%	< 6%
Pozzolanic activity	Moderate to high	Very high
Water demand	Generally low	Generally high
Main function in concrete	Strength and durability improvement	Strength and permeability reduction
Source	Coal combustion by-product	Silicon/ferrosilicon alloy production by-product

V. RESULT OF CONCRETE

A. Compressive Strength

The figures 3 to 5 illustrate the variation in the compressive strength of concrete at 7, 14, and 28 days for different percentages of mineral admixtures used as partial replacements for cement. The seven-day results show the early-age strength development of the concrete mixtures, while the fourteen-day results indicate the continued development of strength with curing. The twenty-eight-day results provide the final strength comparison among the control mix and mixtures containing different proportions of silica fume, rice husk ash, iron slag, and their combined replacement. Overall, the figures demonstrate that the compressive strength varies with the type and percentage of mineral admixture, with optimum replacement levels providing better strength performance than excessive replacement levels.

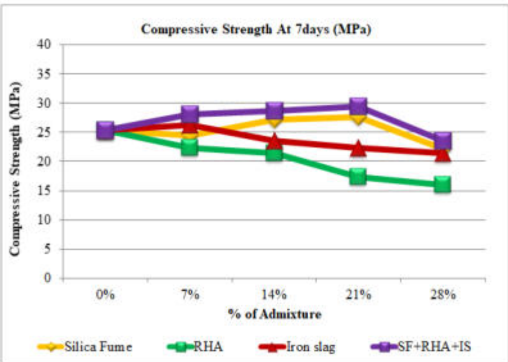

Fig 3: Variation in Seven-Day Compressive Strength with Different Percentages of Mineral Additives

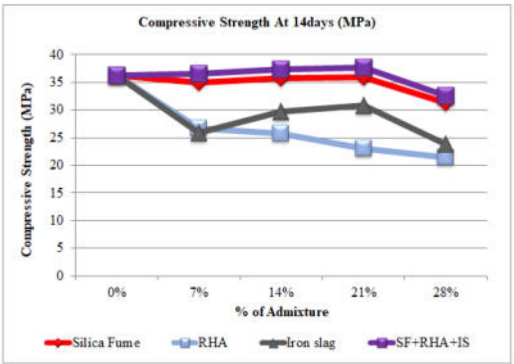

Fig 4: Variation in Fourteen-Day Compressive Strength of Concrete with Different Percentages of Mineral Admixtures

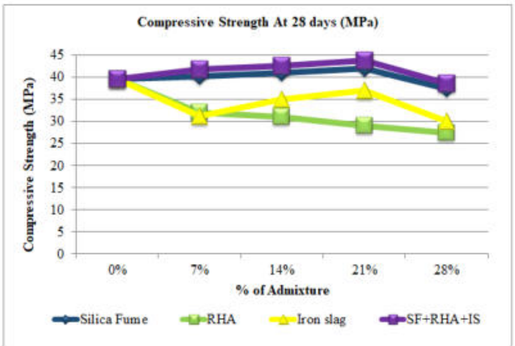

Fig 5: Variation in Twenty-Eight-Day Compressive Strength of Concrete with Different Percentages of Mineral Admixtures

B. Flexural Strength

The flexural strength results at 7, 14, and 28 days show that silica fume generally improved flexural strength up to 21% replacement, beyond which the strength decreased. At 7 days, the strength increased from 4.347 MPa for the control concrete to 4.538 MPa at 21% silica fume. At 14 days, the maximum value was 5.173 MPa at 21% replacement. At 28 days, silica fume achieved a maximum flexural strength of 5.597 MPa at 21%, compared with 5.434 MPa for the control mix, followed by a decrease at 28% replacement. Rice husk ash showed its best performance at 7% replacement, reaching 4.886 MPa at 28 days, while iron slag achieved a maximum of 5.254 MPa at 21% replacement. Overall, the results indicate that optimum replacement levels improve flexural strength, whereas higher replacement levels tend to reduce strength.

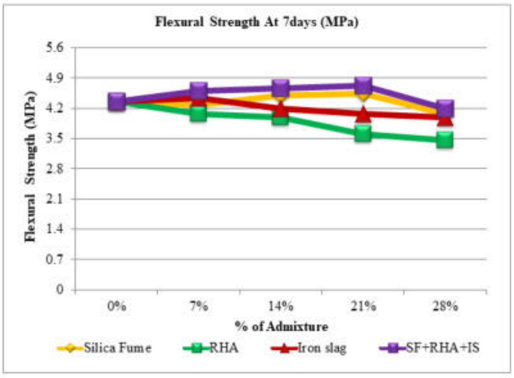

Fig 6: Variation in Seven-Day Flexural Strength of Concrete with Different Percentages of Mineral Admixtures

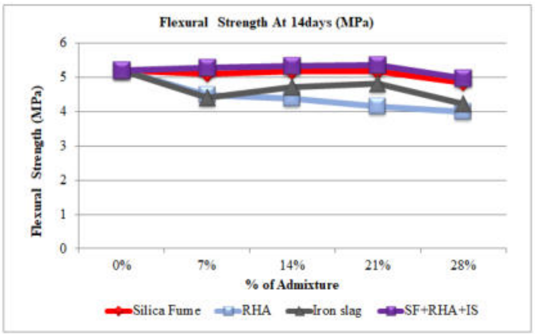

Fig 7: Variation in Fourteen-Day Flexural Strength of Concrete with Different Percentages of Mineral Admixtures

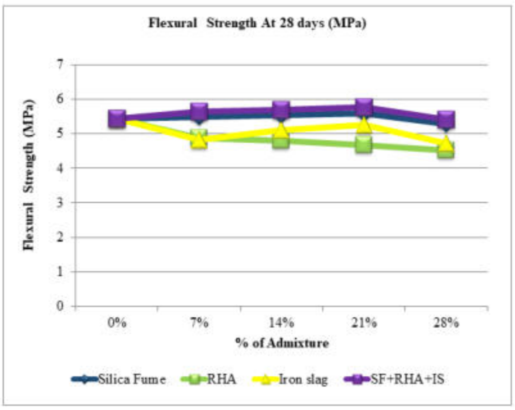

Fig 8: Effect of Mineral Admixture Replacement on the 28-Day Flexural Strength of Concrete

C. Split Tensile Strength

The split tensile strength results at 7, 14, and 28 days indicate that the effect of mineral admixtures depends on their type and replacement level. Silica fume generally showed its optimum performance at 21% replacement, while rice husk ash achieved its highest strength at 7% replacement. Iron slag showed optimum performance at 7% at 7 days and 21% at 14 and 28 days. The combined SF + RHA + IS mixture showed a progressive increase in split tensile strength up to 21% replacement, followed by a decrease at 28%. Overall, the results demonstrate that optimum replacement levels can improve the split tensile strength of concrete, whereas excessive replacement may reduce its performance.

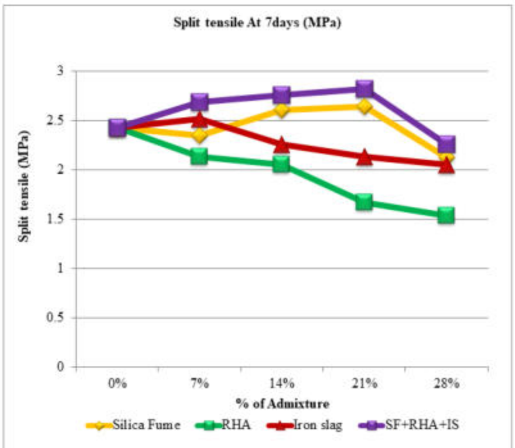

Fig 9: Variation in 7-Day Split Tensile Strength of Concrete with Different Mineral Admixture Replacements

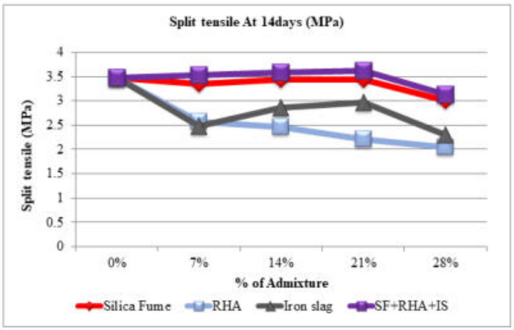

Fig 10: Variation in 14-Day Split Tensile Strength of Concrete with Different Mineral Admixture Replacements

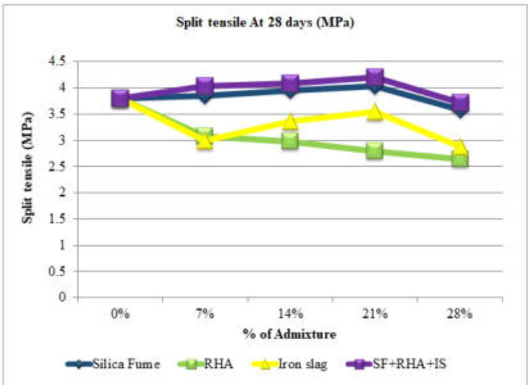

Fig 11: Variation in 28-Day Split Tensile Strength of Concrete with Different Mineral Admixture Replacements

VI. CONCLUSION

The present study evaluated the performance of sustainable concrete incorporating silica fume (SF), rice husk ash (RHA), and iron slag (IS) as partial cement replacements. The results showed that SF and IS provided improved strength at optimum replacement levels, while RHA performed best at a lower replacement level. The combined SF + RHA + IS mixture demonstrated the highest overall mechanical performance, achieving a maximum 28-day compressive strength of 43.80 MPa, compared with 39.58 MPa for the control concrete. The combined mixture also showed improvements in flexural and split tensile strengths. Overall, the optimized use of SF, RHA, and IS can enhance concrete strength while promoting waste utilization, reducing cement consumption, and supporting the development of more sustainable concrete.

References

[1] M. J. Miah, M. S. Miah, and H. Mughal, “Sustainable concrete made with rice husk ash: Comparison with fly ash and blast-furnace slag,” in Proceedings of the 3rd International Conference on Sustainability: Developments and Innovations, vol. 1, pp. 325–333, 2026.

[2] R. Prajapati and H. Rathore, “Performance evaluation of modified concrete incorporating fly ash, silica fume, rice husk ash, and calcium nitrate,” STM Journal of Structural Engineering and Management, vol. 12, no. 2, pp. 35–39, 2025.

[3] B. K. Chaitanya, Y. Madhavi, C. S. S. Durga, M. G. Meharie, C. Venkatesh, A. S. Prasad, G. U. Alaneme, and N. S. V. Kumar, "Performance evaluation of concrete containing fly ash, silica fume and m-sand under high temperatures: Mechanical and microstructural approach," Journal of Infrastructure Preservation and Resilience, vol. 6, Art. no. 31, 2025.

[4] S. S. Pradhan, U. Mishra, S. K. Biswal, and Parveen, "Mechanical and microstructural study of slag based alkali activated concrete incorporating RHA," Construction and Building Materials, vol. 400, 2023.

[5] N. Khandelwal, S. Bhargava, and H. K. Sain, "A study on Kota stone powder slurry and ground-granulated blast-furnace slag as an ingredient in concrete," International Journal of Engineering Science Technology and Research (IJESTR), vol. 7, no. 3, pp. 12–16, 2022.

[6] N. Goyal, H. K. Sain, and M. K. Agwan, "A study on fiber reinforced concrete using different types of geo-polymer fiber in preparation of concrete sample," Journal of Emerging Technologies and Innovative Research (JETIR), vol. 9, no. 9, pp. 750–753, 2022.

[7] H. K. Sain and A. Verma, "An overview and use of Kota stone powder slurry to improve engineering properties of soil stabilization," International Journal of Engineering Trends and Applications (IJETA), vol. 12, no. 4, Jul.–Aug. 2025.

[8] H. K. Sain, V. Sharma, and B. Nisar, "Effect of rock cracks on RC structures," AIP Conference Proceedings, vol. 2901, no. 1, Art. no. 050005, pp. 1–5, 2023.

[9] H. K. Sain and G. Singh, "Utilization of sisal fiber and eggshell waste as sustainable additives in self-compacting concrete," International Journal of Engineering Trends and Applications (IJETA), vol. 12, no. 4, Jul.–Aug. 2025.

[10] D. Meena, M. K. Agwan, and H. K. Sain, "An experimental study on the behaviour of concrete by partial replacement for rice husk ash, silica fume and iron slag with cement," International Journal of Engineering Trends and Applications (IJETA), vol. 10, 2023.