World Journal of Advanced Engineering Technology and Sciences

eISSN: 2582-8266

Cross Ref DOI: 10.30574/wjaets

Journal homepage: https://wjaets.com/

(Review Article)

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Review on Experimental Investigation on Partial Replacement of Cement and Coarse Aggregate by Rice Husk Ash and Steel Slag in Concrete

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World Journal of Advanced Engineering Technology and Sciences, 2026, 18(01), 071-077

Publication history: Received on 24 November 2025; revised on 03 December 2025; accepted on 05 January 2026

Article DOI: https://doi.org/10.30574/wjaets.2026.18.1.0004

Abstract

The importance of concrete in modem society cannot be underestimated. There is no escaping from the impact of concrete on everyday life. Concrete is a composite material which is made of filler and a binder. Typical concrete is a mixture of fine aggregate (sand), coarse aggregate (rock), cement, and water. Nowadays the usage of concrete is increasing from time to time due to the rapid development of construction industry. The usage of concrete is not only in building construction but also in other areas such as road construction, bridges, harbor and many more. Thus technology in concrete has been developing in many ways to enhance the quality and properties of concrete. This study was made to investigate the nature of partial replacement of rice husk ash and steel slag and its influences on the strength properties of concrete. Properties of hardened concrete like compressive strength and workability was determined for different mix combinations of materials and these values are compared with the corresponding values of conventional concrete. Ordinary Portland cement (OPC) was replaced with Rice Husk Ash (RHA) by weight at 0%, 10%, 20% and 30%. And steel slag with Coarse Aggregate by weight at 0%, 20%, 40% and 60%.

Keywords: Rice Husk Ash; OPC; Partial Replacement; Steel Slag

1. Introduction

Concrete is widely and globally used throughout the history of humankind. Concrete is a mixture of sand and crushed rock combined together by a hardened paste of hydraulic cement and water. The increased use of concrete is going to grow the demand for its ingredients' resources (cement, sand, and gravel). [2] The high rate of concrete constituents is increasing rapidly and hence there is a requirement for an unconventional material that is low-cost and readily presented that will also give a similar or greater strength when used for concrete. [5]

Concrete is a composite material composed primarily of aggregate, cement and water. There are many formulations that have varied properties. [6] The utilization of concrete in increasing at a higher rate due to development in infrastructure and construction activities all around the world. Now a days due to huge demand of concrete in construction work. it is essential to developed or find such sources or material which can replace sand and course in concrete aggregate is the most common material in concrete it occupies more than 70-80% of total volume in concrete and it provides strength to the concrete. [4]

1.1. Rice Husk Ash

Rice husks are the hard protective coverings of rice grains which are separated from the grains during milling process. Rice husk is an abundantly available waste material in all rice producing countries, and it contains about 30%–50% of organic carbon. In the course of a typical milling process, the husks are removed from the raw grain to reveal whole brown rice which upon further milling to remove the bran layer will yield white rice. [3] Current rice production in the

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world is estimated to be 700 million tons. Rice husk constitutes about 20% of the weight of rice and its composition is as follows: cellulose (50%), lignin (25%–30%), silica (15%–20%), and moisture (10%–15%). Bulk density of rice husk is low and lies in the range 90–150 kg/m3. [7]

Figure 1 Rice Husk Ash

Table 1 Properties of Rice Husk Ash[3] [7] [16]

Sr. No.	Properties	Specifications
1	Specific Gravity (g/cm^3)	2.11 to 2.27
2	Diameter (micron)	5 micron (ultra-fine particles) and 95 micron
3	Density (kg/m^3)	90–150 kg/m3

1.2. Steel Slag

Steel slag is an industrial by product obtained from the steel manufacturing industry. It is produced in large quantities during steel-making operations that use electric arc furnaces. Steel slag can also be produced by smelting iron ore in a basic oxygen furnace. [11] In addition, steel slag can be used as aggregates in concrete to replace natural aggregates, because it has favorable mechanical properties, including strong bearing and shear strength, good soundness characteristics, and high resistance to abrasion and impact. Steel slag aggregates are fairly angular, roughly cubical pieces with a flat or elongated shape (as shown in Figure 2). [25] They have a rough vesicular nature with many non-interconnected cells, which gives a greater surface area than smoother aggregates of equal volume. [20] This feature provides an excellent bond with concrete binder. Replacing some or all-natural aggregates with steel slag is helpful for reducing environmental pollution and the consumption of resources. Therefore, steel slag is a promising kind of filler because it works as both functional filler and aggregate. The incorporation of air-quenching steel slag of 0.315–5 mm. [19]

Figure 2 Steel Slag

Table 2 Properties of Steel Slag [11] [25] [19] [20]

Sr. No.	Properties	Specifications
1	Specific Gravity (g/cm^3)	3.2 - 3.6
2	Diameter (micron)	0-15 µm, 15-30 µm, 30-45 µm and 45-80 µm
3	Density (kg/m^3)	1600 - 1920

1.3. State Of Development

The integration of industrial and agricultural by-products in concrete has gained considerable attention to promote sustainability and reduce environmental burdens. Rice Husk Ash (RHA) and Steel Slag (SS) are two promising alternative materials widely explored in recent studies due to their pozzolanic and mechanical enhancement properties.

Table 3 State of Development

Sr. No.	Author Name	Year	Findings
1	Paul et al.	2024	Investigated compressive strength prediction of RHA-based concrete using AI models (CatBoost, GBM, CNN, GRU). GRU showed highest accuracy. Confirmed RHA's sustainability and greenhouse gas reduction potential. [16]
2	Murmu et al.	2023	40% steel slag as coarse aggregate improved compressive strength (20.55%), split tensile (27.55%) & flexural (10.55%). Strength decreased at higher replacement or fine slag use. [11]
3	Jaglan et al.	2023	20% regulated RHA in unfired compressed blocks provided optimum mechanical performance and improved waste management. [7]
4	Ren et al.	2023	Review showed steel slag enhances strength & durability but untreated slag causes expansion; pre-treatment recommended. [25]
5	Bertoldo et al.	2023	RHA & wood ash as fine aggregate replacement provide compressive strength comparable to conventional concrete with carbon sequestration benefits. [3]
6	Rajendran et al.	2022	20% steel slag as fine aggregate improved compressive (8%), tensile (7.5%), flexural (40.6%) strengths with practical pavement applications. [10]
7	Mounika et al.	2021	RHA up to 30% enhances strength, reduces density, and improves durability due to high pozzolanic reactivity. [13]

8	Sinha et al.	2021	Steel slag replacement up to 75% feasible in M20 & M30 grades depending on mix design and replacement ratio. [19]
9	Piemonti et al.	2021	Review emphasized increased steel slag production, durability advantages, and need for improved utilization strategies. [20]
10	Gencel et al.	2021	Steel slag enhances strength & sustainability; improves physical, chemical, and mechanical performance. [22]
11	Jain et al.	2021	RHA reduces workability due to high water absorption but remains a sustainable binder with acceptable strength. [12]
12	Sam et al.	2020	Best result with 7.5% RHA + 30% fly ash; RHA reactivity depends on burning conditions. [8]
13	Bheel et al.	2019	10% RHA replacement improved compressive strength by 11.8% and tensile by 7.31%, though flowability reduced. [6]
14	Amin et al.	2019	RHA (10–30%) improved strength and reduced permeability more effectively than fly ash. [2]
15	Jongpradist et al.	2018	RHA up to 35% increased strength of cement-admixed clay blends by >100%, outperforming fly ash in high-strength soil-cement systems. [14]
16	Zareei et al.	2017	15–20% RHA + microsilica gave best high-strength concrete performance with ~20% improvement in durability. [4]
17	Palod et al.	2017	Steel slag + GGBS produced comparable strengths; slag alone caused instability at high ratios. [21]
18	Chandini et al.	2017	Steel slag as fine aggregate improved strength and durability while reducing quarrying and disposal issues.[23]
19	Sharma et al.	2016	20% RHA replacement gave optimum compressive strength in M20 concrete while reducing CO_2 emissions. [5]
20	Subathra Devi et al.	2014	Steel slag as coarse aggregate improved strength; performance depends on controlled processing due to chemistry variation. [17]

2. Review of Experimental Studies

Rapid urbanization and infrastructure growth have significantly increased the demand for cement and natural aggregates in the construction sector. However, conventional concrete production contributes heavily to CO_2 emissions, resource depletion, and solid waste disposal challenges. To address sustainability, researchers are focusing on alternative industrial and agricultural wastes as supplementary cementitious materials (SCM) and aggregate replacements. [17]

Rice Husk Ash (RHA) is an agro-industrial byproduct rich in amorphous silica, exhibiting high pozzolanic activity when burnt under controlled temperatures. Similarly, Steel Slag (SS) is a byproduct of steel manufacturing with excellent mechanical and durability properties, making it an effective coarse aggregate substitute. [11] [6] [7]

2.1. Importance of RHA and Steel Slag in Concrete

Table 4 Importance of RHA and Steel Slag in Concrete [3] [7] [11] [25]

Parameter	**Rice Husk Ash (RHA)**	**Steel Slag (SS)**
Source	Agricultural waste	Metallurgical waste
Chemical Strength	High pozzolanic reactivity (SiO_2 > 85%)	High CaO and Fe_2O_3 improving bonding
Sustainability Benefit	Utilizes agro waste & reduces cement consumption	Conserves natural aggregates & reduces landfill waste

Concrete Benefits	Improved strength & durability, lower permeability	Higher compressive and tensile strength due to rough, angular surface

2.2. Studies on Rice Husk Ash

10–30% RHA enhances compressive and tensile strengths due to secondary C–S–H gel formation. [4] Workability reduces because of finer and porous RHA particles → requires super plasticizers. Chloride permeability and water absorption decrease improving durability. Optimal replacement commonly found at 15–20%. [5]

2.3. Studies on Steel Slag

30–50% SS replacement gives maximum mechanical performance. [20] Excellent bonding due to rough texture & high density. [21] Concerns include volume expansion if slag is untreated (presence of free lime). Better performance in pavements and high-strength concrete. [22]

Table 5 Combined Effect of RHA and Steel Slag [4] [5] [20] [21] [22]

Property	Effect of RHA	Effect of Steel Slag	Combined Synergy
Strength	Improves cement matrix	Increases aggregate strength	Stronger interfacial transition zone (ITZ)
Durability	Reduces permeability	Improves abrasion resistance	Useful in marine & pavement structures
Sustainability	Reduces CO_2 emissions	Reduces mining	Dual waste management

3. Conclusion

The review of existing literature on the partial replacement of cement using Rice Husk Ash (RHA) and coarse aggregates using Steel Slag (SS) demonstrates that both materials exhibit excellent potential in the development of sustainable concrete. RHA, being highly rich in amorphous silica, acts as an effective pozzolanic material which enhances the hydration process by forming additional C–S–H gel. This leads to improved strength and reduced permeability. Similarly, the rough, angular texture and high hardness of steel slag provide better mechanical interlocking within the concrete matrix, contributing to increased load-bearing capacity and superior abrasion resistance.

The reviewed studies reveal that using 10–20% RHA as cement replacement and 30–50% steel slag as coarse aggregate replacement generally yields optimum improvements in compressive, split tensile, and flexural strengths. Furthermore, the integration of both waste materials significantly improves resistance against chloride penetration, chemical attack, and water absorption, resulting in improved durability performance. Although workability tends to decrease due to the high surface area of RHA, appropriate use of superplasticizers effectively mitigates this issue.

From an environmental standpoint, replacing cement with RHA contributes to noteworthy reductions in CO_2 emissions and addresses agricultural waste disposal challenges. Likewise, utilization of steel slag helps in minimizing landfill demands and reduces over-dependence on natural aggregates. Hence, the combined incorporation of RHA and SS supports the concept of circular economy and green construction initiatives.

Despite the promising results, the study also identified certain research gaps. Issues such as volume instability in untreated steel slag, lack of standardized processing methods, limited long-term durability data, and insufficient optimization for combined RHA–SS mixes require further investigation. Additionally, few studies examine microstructural interactions and performance under extreme service conditions.

In conclusion, the partial replacement of cement with RHA and coarse aggregate with steel slag is a highly beneficial strategy to enhance mechanical performance, improve environmental sustainability, and conserve natural resources. The reviewed literature strongly indicates that such innovative concrete solutions can significantly contribute to the future of sustainable infrastructure development. However, further experimental studies and field validations are essential to establish standardized guidelines and ensure large-scale practical implementation.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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