Indian Journal of Engineering & Materials Sciences
Vol. 32, December 2025, pp. 755-764
DOI: 10.56042/ijems.v32i06.22951

Characterization and performance evaluation of wheat husk ash for sustainable and durable concrete production

Aditi Patidar[a,b*] & Janardan Singh Chauhan[b]

[a]Department of Civil Engineering ,IPS Academy, Institute of Engineering & Science Indore 452 012, Madhya Pradesh, India
[b]Department of Civil Engineering, Samrat Ashok Technological Institute, Vidisha 4640 01, Madhya Pradesh, India

Received: 21 August 2025; accepted: 6 November 2025

The increasing demand for sustainable construction materials has encouraged the utilization of industrial and agricultural by-products as alternatives to conventional cementitious materials. These wastes have been recognized as cost-effective, readily available, and capable of significantly reducing environmental pollution when reused in construction applications. This study has examined the feasibility of using wheat husk ash (WHA), an agricultural residue rich in amorphous silica, as a partial replacement for cement in concrete. Concrete mixtures have been prepared by replacing cement with WHA at levels ranging from 10% to 25% by mass, with water-to-cement ratios between 0.30 and 0.40. An extensive experimental program has been conducted to evaluate the influence of WHA as a supplementary cementitious material on the fresh, physical, and hardened properties of concrete. Fresh properties have been evaluated through workability measurements, while physical properties have included density and water absorption. Hardened properties have been assessed in terms of compressive strength and overall mechanical performance. The results have indicated that incorporating WHA up to an optimum replacement level has improved concrete performance due to enhanced pozzolanic activity and micro structural densification. Beyond the optimum content, reductions in strength and workability have been observed. Overall, the findings have demonstrated that wheat husk ash can be effectively utilized as a sustainable cement replacement material, contributing to reduced cement consumption and improved environmental sustainability in concrete construction.

Keywords: Durability, Mechanical properties, Polycarboxylates, Sustainable Concrete, Wheat Husk, Ash XRD

1 Introduction

Cement, fine aggregate, and coarse aggregate are all components of concrete; the majority of these materials are obtained from natural resources. Due to technical advancements, rising standards of living, growing urbanization, and rising population have increased the demand for natural resources in the building sector, leading to resource scarcity. The researchers are motivated by the lack of resources to utilize solid wastes produced by commercial, industrial, home, and agricultural operations. It has been noted that India has produced more than 600 tonne of garbage from agricultural waste, which is substantially complicating the issue of disposal.

Reusing these wastes as environmentally friendly building materials eliminates the problems of contamination, area filling, and building material costs Prusty[1]. Recycling agricultural waste can solve both environmental preservation and a scarcity of building materials. Recent research emphasizes the need to recycle garbage rather than dump it in public areas to protect the ecosystem. Due to their abundance, accessibility, ecological friendliness, non-toxicity to humans, lightweight, cost-saving potential, and abundance, renewable resources have gained attention in scientific circles. These raw materials can also be utilized as an inexpensive supply of silica for commercial applications including the production of glass and pharmaceuticals. This study found that using agricultural waste as a partial replacement produces concrete that is less harmful to the environment Masanja[2]. The level of silica in wheat husk ash was also found to be acceptable, which is essential if these raw materials are to be used as supplementary cement ingredients in concrete Zaid[3].

Every summer, a sizable amount of wheat husk is generated. Farmers destroy the ecosystem when they burn it. Wheat husk may be used to make mud bricks instead of being burned. Similar environmental impact can result from large volumes of organic waste like wheat cob and leaves. If burnt, these materials might also be used as pozzolanic materials in the creation of long-lasting concretes. Silica dioxide, or SiO_2, is known to be present in significant amounts in wheat

---

*Corresponding author (E-mail:aditipatidar@ipsacademy.org) cob. Once burnt, it produces an ash that is pozzolanic in nature and highly rich in SiO_2 Binici[4]. Figure 1 illustrates wheat husk and wheat husk ash, highlighting their pozzolanic characteristics, which contribute to the enhancement of compressive strength.

Numerous unsaturated biochars, for example, bagasse biochar (BB), nut husk biochar (PHB), rice husk biochar (RHB), and wheat husk biochar (WHB), were added to cement pastes at dosage rates ranging from 1 to 5 weight percent. According to estimates, biochars have a CO_2 adsorption capability of 1.25 to 1.72 mmol/g. A great source of CO_2 adsorption, biochar aids in the sequestration of carbon. Furthermore, by allowing biochar to adsorb CO_2 until the pores are filled, emissions of about 300 kg CO_2 per tonne of dry feedstock can be reduced (CO_2 adsorption of 7 mmol/g) Eker[5]. Utilizing biochar is analogous to using carbonate fines in cementitious materials to sequester carbon. The concrete industry has recently implemented several cutting-edge strategies to reduce its carbon impact. These attempts involve adding waste and recyclable materials as binders and aggregates to concrete mixtures. However, the majority of these programs combine the use of these energy-inefficient concrete building techniques with the use of these ecologically friendly elements. The necessity of substituting conventional components and production methods increases energy consumption and carbon dioxide emissions into the environment Bheel[6]. Agricultural residue ashes (ARAs) have good pozzolanic characteristics and may be utilized effectively as supplemental cementitious materials, according to research. They have a broader range of particle sizes and a strong pozzolanic efficiency, which can improve the microstructure of ITZ Qudoos[7]. The thick nanostructure of cement composites is caused by calcium silicate hydrate, which is produced in greater quantity by the latter and lessened by the former Schiavon[8].A significant volume of wheat husk is produced as a result of the industrial processing of cereal., According to the weight correlation of around 5:1 between wheat and husk production, we may estimate that more than 2610 t of wheat husk are supplied each year in the European Union, which is 2.6 times the amount suggested in our prior assessment. It is possible to burn wheat husk to produce heat or electricity, however, this involves pre-treatment of the raw ingredients Cappucci[9].

One of the most prevalent by products of the processing of this dish is the wheat spike and husk. This waste may be used to create a variety of products, including SiO_2-activated carbon and elemental Silicon. Resources like cement-based material, a binding substance, and pebbles like coarse and fine aggregates are currently scarce. This wonderful material is heavily dependent on the building sector. Therefore, it's important to introduce cheap, residual materials with pozzolanic qualities with the potential to replace traditional concrete materials to decrease the destruction of natural resources Chen[10].

Ash from agricultural residues (ARAs), the majority of which result in landfills, poses a huge hazard to the environment. ARAs such as WHA and Stover dirt corn both have high silica content, which makes them good pozzolanic materials.

These materials include silica, which combines with calcium hydroxide (CH), a cement hydration product, to create new hydration products Qudoos[11].Due to their high silica concentration and inexpensive price, wheat husk ash (WHA) is one of the several ARAs that is widely utilized as a pozzolanic. The pozzolanic activity of WHA was investigated through several experiments. The findings of these investigations show that the well-burnt WHA's improved pozzolanic activity is due to its large specific area of surface, high concentration of silica, and porous morphology.WHA incorporation led to an improvement in compressive property, low permeability, and resistance to acid and chloride attack Chin[12]. It has also been demonstrated that wheat

Fig. 1 — (a) Wheat husk pile, (b) Ash generation by burning (c) Wheat husk ash.

husk ash (WHA) reveals pozzolanic characteristics. Numerous studies have looked at the effectiveness of WHA as an additive and pozzolanic component in composites made of cement. According to reports, adding WHA improved the cement mortars' strength in both flexion and compression. WHA's filling action led to the improvement of mechanical characteristics. Scientific literature has been reported on the improvement in the cement compound's long-lasting properties using WHA. In prior work, the scientists looked at how mechanical processing affected the hydration properties of wheat husk ash Naqvi[13].

2 Materials and Methods

The stones utilized for this research were crushed into coarse aggregates (CAs) with a Size of 20 mm, hilly sand was employed for a field investigation, and the fine particles used were processed through a 4.75 mm.

The purpose of this study is to turn the residue from these crops into ashes and determine whether they may be used as pozzolans in cement. The analysis of the aggregate sieve is computed. In this experiment, the ASTM C150 compliant chemical and physical properties of typical Portland cement type I were used. In addition to that, the fine aggregate consisted of crushed sand with a maximum grain size of 4.75 mm, a fineness modulus of 2.6, a specific gravity of 2.61, and water absorption of 1.73%. Crushed stone with a specific gravity of 2.67, a water absorption capacity of 0.47, and a maximum nominal size of 20 mm was utilized as the coarse aggregate.

To produce an appropriate firmness with an appropriate water/binder (w/b) proportion, a polyether-Polycarboxylates PCE-based super plasticizer (SP) is necessary.

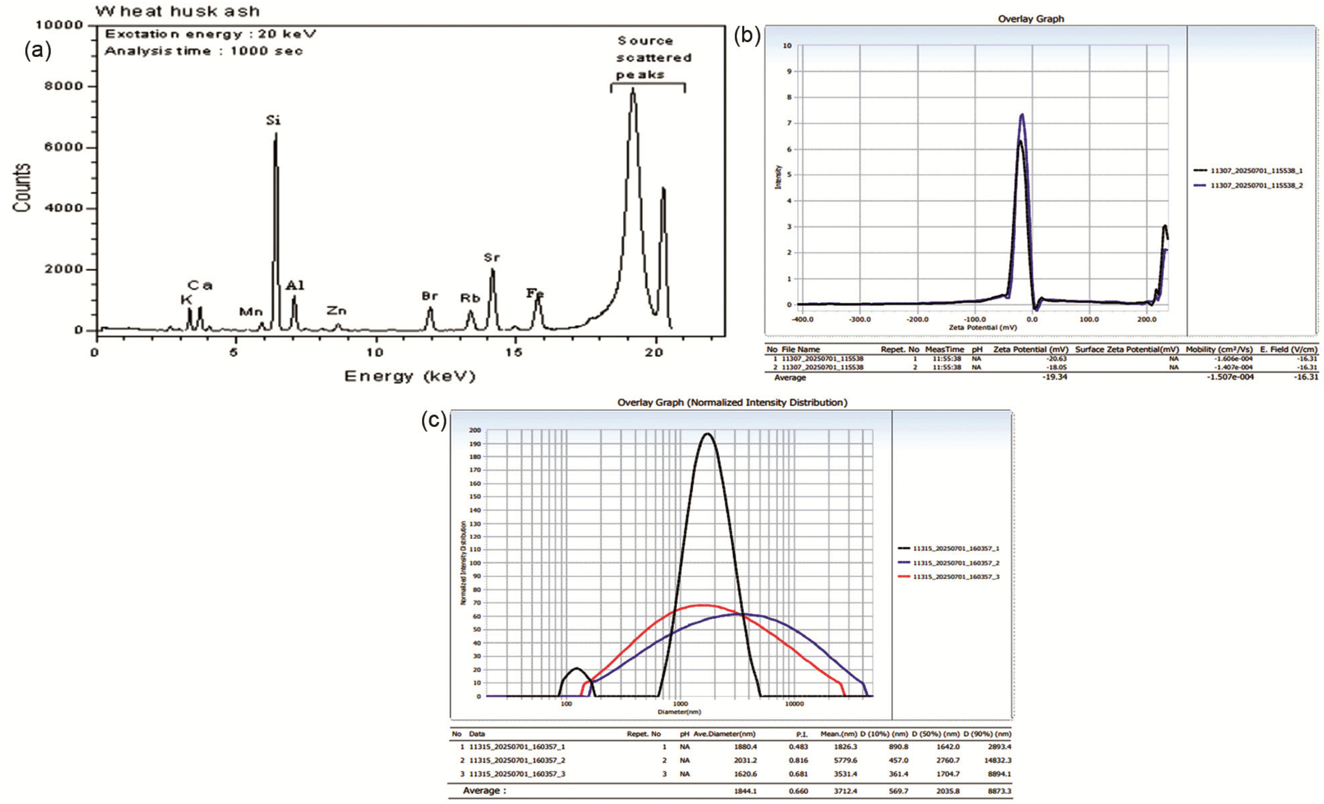
2.1 Characterization of wheat husk ash

When wheat husk is burned, its cellular structure decomposes, releasing its cellulose-lignin components and forming porous ash. This ash primarily consists of silica, along with minor traces of alkali and other elements. The silica content, particle size, and specific surface area are influenced by factors such as the source of the husk, the incineration method used, and the combustion temperature. Wheat husk ash (WHA) is recognized as a pozzolanic material. When the amorphous silica (SiO_2) present in WHA reacts with calcium hydroxide during the cement hydration process, it results in the formation of additional calcium silicate hydrate (C-S-H) gel. This enhances the mechanical strength and durability of the concrete. Among the hydration by-products, calcium hydroxide (CH) is the most soluble and is often considered a "weak link" in concrete, compromising its long-term durability.

Amorphous silica is typically produced when wheat husks are burned at temperatures between 350°C and 750°C, whereas crystalline silica forms at temperatures exceeding 800°C Cizer[14]. Due to its high silica content, availability, siliceous nature, and cost-effectiveness, WHA has gained significant attention from researchers as a potential partial replacement for cement in concrete production Javed[15.] The preparation of wheat husk ash (WHA) is influenced by two key factors: the burning temperature and the grinding process. Several studies have explored how incineration conditions affect the composition of WHA, particularly the proportion of amorphous silica it contains. Researchers have found that maintaining a controlled temperature and duration during the burning process can yield highly reactive, amorphous silica.

Specifically, keeping the incineration temperature below 800°C under oxidizing conditions or exposing the wheat husk to 550°C for just one minute results in the formation of this desirable amorphous phase. However, if the temperature or burning time exceeds this range, the silica transitions into its crystalline form Liu[16.] Silicon dioxide (SiO_2) is the primary chemical component of wheat husk ash (WHA), which exists as fine particulate matter. This composition is responsible for WHA's pozzolanic activity. In addition to silica, WHA contains other elements like aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), calcium oxide (CaO), magnesium oxide (MgO), titanium oxide (TiO), phosphorus pentoxide (P_2O_5), sulfur trioxide (SO_3), sodium oxide (Na_2O), and traces of unburned carbon. The composition of these elements can vary not only between different plants but even within the same plant. Typically, the two primary components fluctuate as follows: residual carbon content (loss on ignition) $\leq 12\%$, and SiO_2 content exceeding 40%. The structure of WHA is predominantly made up of amorphous (non-crystalline) silica. WHA is obtained by burning wheat husk in a moderately oxidizing environment, maintaining a controlled temperature between 500°C and 800°C for an appropriate duration, usually ranging from 15 minutes to 4 hours. This controlled process ensures a high concentration of amorphous silica in the final product Shinohara[17]. In the current study, various forms of wheat husk ash (WHA) were produced by burning wheat husk at five different temperatures — 400°C, 500°C, 600°C, 700°C, and 800°C — over three distinct durations of 1, 2, and 4 hours. WHA was obtained by burning the husk in a moderately oxidizing environment, maintaining a controlled temperature between 400°C and 800°C for an appropriate period. Chemical analysis revealed that the WHA sample burned for four hours at 500°C had the highest silica content. The primary component of WHA is silica (SiO_2), predominantly in an amorphous form. Figure 2 shows the zeta potential, normalized Intensity Distribution, and XRF graph, which clearly indicates the presence of chemical constituents in wheat husk ash.

Generally, WHA consists mostly of silica, making up more than 70% of its total weight. However, it also contains varying amounts of other compounds, such as potassium oxide (K_2O) and aluminum oxide (Al_2O_3), which cannot be overlooked. Additionally, at later stages of combustion, the residual carbon content, measured by the loss on ignition (LOI), becomes relatively significant. As per ASTM C 350-1954 standards; fly ash should contain at least 40% SiO_2 to ensure sufficient silica availability for the formation of additional calcium silicate hydrate (C-S-H) gel during the cement hydration process with calcium hydroxide (CH). Although WHA is not officially classified, it should be considered similar to fly ash due to its comparable chemical composition and behavior. Using X-ray fluorescence (XRF), the chemical makeup of wheat husk ashes and cement samples was investigated. The XRF results are summarized in Table 1, WHA includes silica (SiO_2) and alkaline (K_2O) chemicals, as given in Table 1, which help to lessen concrete's porosity and prevent rust.



No	File Name	Repet. No	MeasTime	pH	Zeta Potential (mV)	Surface Zeta Potential(mV)	Mobility (cm²/Vs)	E. Field (V/cm)
1	11307_20250701_115538	1	11:55:38	NA	-20.63	NA	-1.606e-004	-16.31
2	11307_20250701_115538	2	11:55:38	NA	-18.05	NA	-1.407e-004	-16.31
Average					-19.34		-1.507e-004	-16.31

No	Data	Repet. No	pH	Ave.Diameter(nm)	P.I.	Mean.(nm)	D (10%) (nm)	D (50%) (nm)	D (90%) (nm)
1	11315_20250701_160357_1	1	NA	1880.4	0.483	1826.3	890.8	1642.0	2893.4
2	11315_20250701_160357_2	2	NA	2031.2	0.816	5779.6	457.0	2760.7	14832.3
3	11315_20250701_160357_3	3	NA	1620.6	0.681	3531.4	361.4	1704.7	8894.1
Average :				1844.1	0.660	3712.4	569.7	2035.8	8873.3

Fig. 2 — (A) X-ray analysis of sample; (B) Zeta potential graph of wheat husk ash; (C) Normalized Intensity Distribution of wheat husk ash.

Table 1 — Oxide content sof OPC and WHA (% by mass) during analysis from XRF results.

Chemical compounds (%)	Cao	SiO_2	Al_2O_3	MgO	Fe_2O_3	SO_3	K_2O	Na_2O	TiO_2	MnO	P_2O_5	L.O.I.
OPC	64.4	20.99	4.05	1.05	3.9	2.92	0.78	0.15	0.35	0.28	0.12	2.18
WHA	1.5	42.05	5.25	1.6	5.60	0.50	1.23	0.29	0.30	0.40	0.26	3.16

2.2 X-ray diffraction (XRD)

A particle size detector was used to measure the particle size distribution of the ashes produced from the grinding of WHA at each stage. Using a surface area detector and the BET technique, the specific surface area of the wheat husk was calculated.

By using X-ray fluorescence (XRF), the chemical content of the wheat husk ash samples was discovered. Using an X-ray diffract meter, the presence of crystalline and amorphous phases of SiO_2 was found in the ash specimens. After 28 days of curing, the ASTM C39-recommended cube sample underwent a compression strength test.

The ash specimen's X-ray diffraction (XRD) pattern is shown in Fig. 3, where it reveals quartz peak locations as well as a hump between 20 to 30 degrees that denotes the amorphous phase of WHA. According to Fig 4, SEM analysis was used to look into the particle shape of the wheat husk ash samples after each stage of grinding. Quartz and particles with porous cellular structures are both present in the WHA specimens. After grinding, the cellular particles were broken up, producing more consistently shaped particles overall concrete that is less dense and eventually increasing weight loss Bheel[18].

2.3 Scanning electron microscopy (SEM)

Wheat husk ash micro structural characterization is crucial because it has a substantial impact on the WHA blended cementitious system's performance, particularly its strength and durability attributes. Studying the microstructure of different WHA enables one to anticipate how the ashes will behave when mixed with concrete. Micrographs of WHAs taken into consideration for the study are shown in Fig. 4. Figure 4 Shows that the WHA structure has pores with diameters ranging from nanometers to micrometers.

A greater surface area of WHA results from these pores. Few WHA particles were discovered to be elongated, and WHA particles were seen to be very irregular. To obtain specimens for the SEM studies, the cube specimen pieces utilized for the micro hardness test were employed. The techniques outlined were used to acquire and prepare the specimens for SEM examination Amin[19].

WHA samples were analyzed using SEM at 500X magnification, as illustrated in Fig. 4. The porosity of the cement matrix is reduced in the paste specimen that contains 20% WHA replacement, which exhibits larger holes between hydration products of more calcium silicate hydrate. Secondary calcium silicate hydrate is created when pozzolanic silica combines with calcium hydroxide. This results in the conversion of big pores into small pores, which considerably aids in decreasing porosity and boosting cement paste strength Bledzki[20].

2.4 Proportions of a mixture

In the present research, varied Water Binder Ratios (W/B) (0.30, 0.35, and 0.40) and wheat husk ash concentrations (WHA) (0%, 10%, 15%, 20%, and 25%) were employed to produce various mixtures in various proportions. The component proportions of the 15 concrete mixtures. The designs are summarized in Table 2.

The best WHA replacement for each w/b ratio must be found if sustainable concrete is to function effectively. Otherwise, adding WHA over the best substitute can reduce the mechanical and durability aspects of sustainable concrete. There were 15 mixes

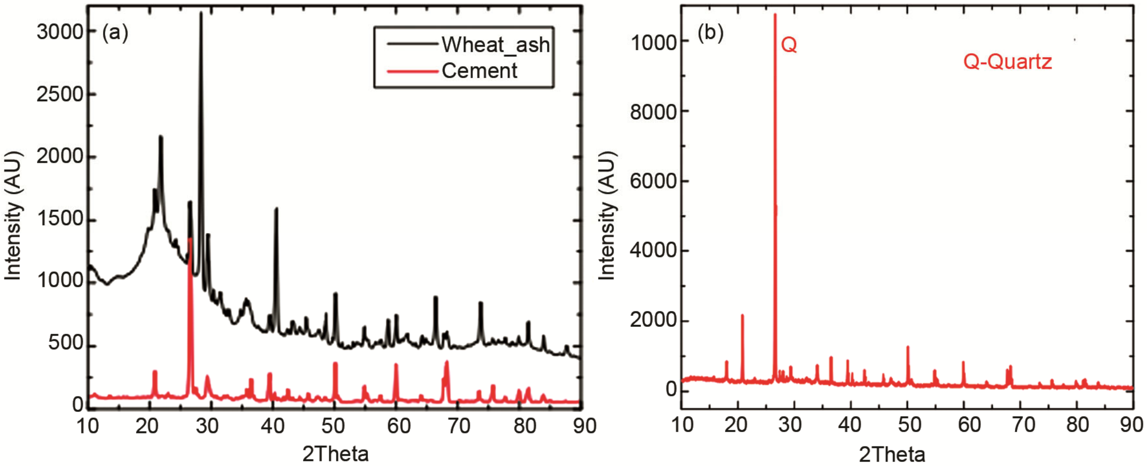


Fig. 3 — (a) XRD pattern of wheat husk ash & cement and (b) XRD pattern of wheat husk ash concrete sample.

in all, and each mix had 27 cubes produced from various sources. Table 2 lists the particular traits of 15 combinations in detail Bheel[21].

2.5 Procedure for combining and preparing specimens

A concrete mixture incorporating pozzolanic was first made by mixing sand and gravel particles for 30 seconds. After combining the pertinent pozzolanic with the cement, the resultant mixture was added to the original mixture and mixed for sixty seconds in the mixer. After that, a liquid mixture including super plasticizers and water was gradually added to the mixer for 30 seconds, after which it was stirred for a further two minutes to achieve the saturated surface dry condition for the aggregate moisture level Patidar[22].

The stone and sand aggregates were initially mixed for thirty seconds in the blender, followed by the addition of the cement and stirring for sixty seconds to create plain concrete. a liquid formulation of super plasticizers with water was then gradually added to the initial slurry for 30 seconds to achieve the required workability for concrete Hameed[23].

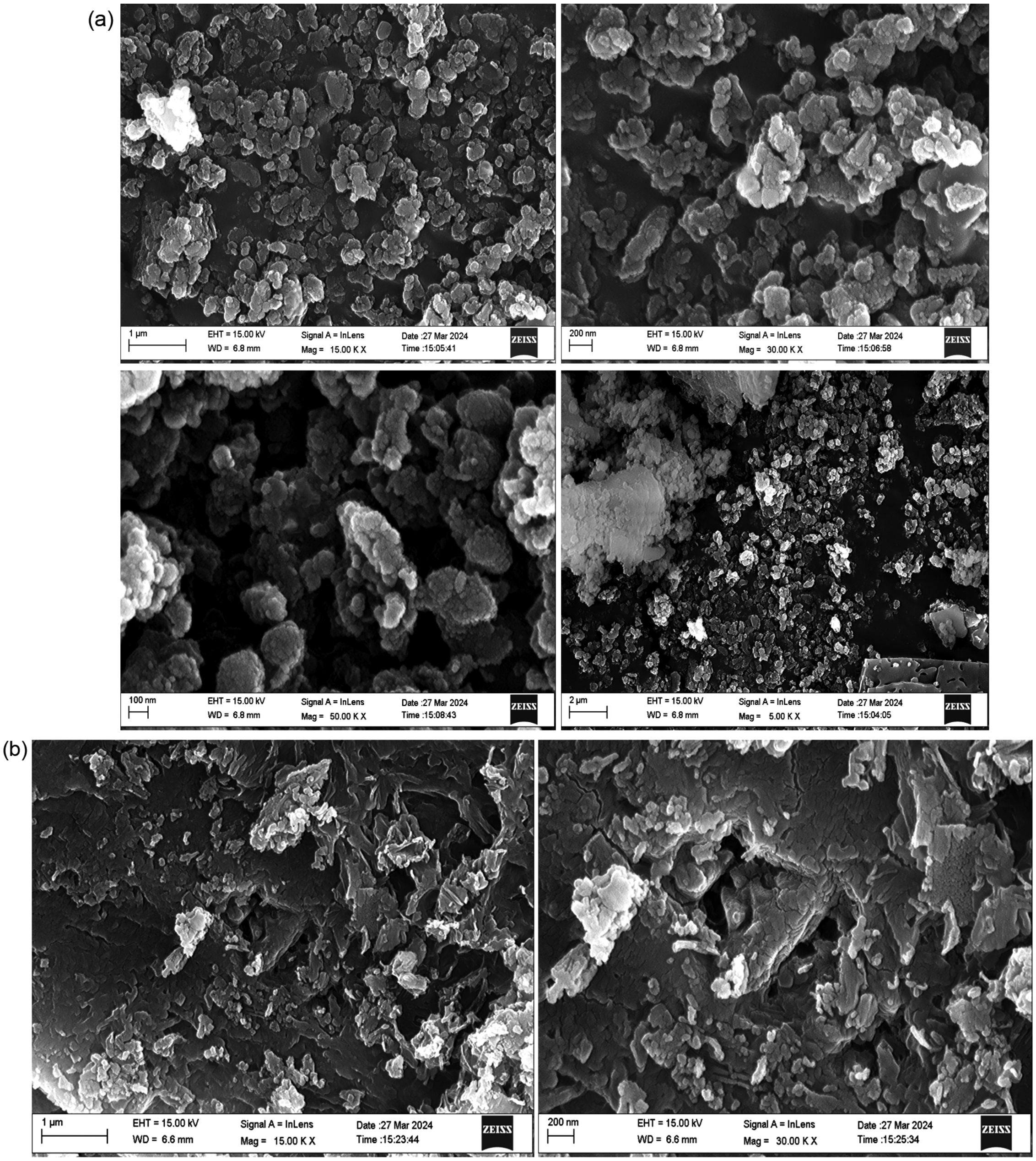


Fig. 4 — (A) SEM Image of (a) WHA material and (b) 20% WHA concrete sample.

Table 2 — proportions for the concrete sample mixture.

w/b	Ratio	WHA	Content (%)	Water (kg/m^3)	Cement (kg/m^3)	WHA (kg/m^3)	Fine aggregates (kg/m^3)	Coarse aggregates (kg/m^3)	Super plasticizer (kg/m^3)
W1	0.30	WHA1	0	134.106	447.02	-	629.9154	1264.942	4.4702
		WHA2	10	134.106	402.318	44.702	633.7521	1272.646	4.4702
		WHA3	15	134.106	379.967	67.053	631.2335	1267.589	4.4702
		WHA4	20	134.106	357.616	89.404	628.7148	1262.531	4.4702
		WHA5	25	134.106	335.265	111.755	626.1962	1257.473	4.4702
W2	0.35	WHA1	0	134.106	383.16	-	667.5019	1282.393	3.8316
		WHA2	10	134.106	344.844	38.316	672.1922	1291.404	3.8316
		WHA3	15	134.106	325.686	57.474	669.9699	1287.134	3.8316
		WHA4	20	134.106	306.528	76.632	667.7476	1282.865	3.8316
		WHA5	25	134.106	287	95.79	665.5252	1278.595	3.8316
W3	0.40	WHA1	0	134.106	335.265	-	701.2764	1289.704	3.35265
		WHA2	10	134.106	301.7385	33.5265	706.6722	1299.627	3.35265
		WHA3	15	134.106	284.9753	50.28975	704.6722	1295.949	3.35265
		WHA4	20	134.106	268.212	67.053	702.6721	1292.27	3.35265
		WHA5	25	134.106	251.4488	83.81625	700.672	1288.592	3.35265

Fig. 5 — (a) Cubes in curing tank, (b) Slump cone test and (c) Compressive testing machine.

The resulting slurry was agitated for two minutes after that. After the concrete mixtures were prepared, their slump values were determined. Following this, three layers of freshly mixed concrete were cast into the molds, and each layer was compacted using 25 strokes of a compacting rod. Using a vibration table, the concrete specimens were further compressed and had their air bubble content reduced after being cast in the molds. Following a 24-hour curing period, the specimens of concrete were taken out of the molds and put into a container of clean water that was kept at a constant 20°C and a relative humidity of 100 percent for no less than 28 days as shown in Fig. 5 Kiran[24].

3 Results and Discussion

3.1 Characteristics of freshly constructed concrete

The usefulness of new cement regardless of the presence of WHA as a substitute for OPC is displayed in Fig. 6 It tends to be seen that the normal downturn results were 103 mm, 78 mm, 69 mm, 63mm, and 59mm for WHA0, WHA10, WHA15, WHA 20 and WHA25, respectively, for 0.35 water cement ratio which is lower compared to sample C.

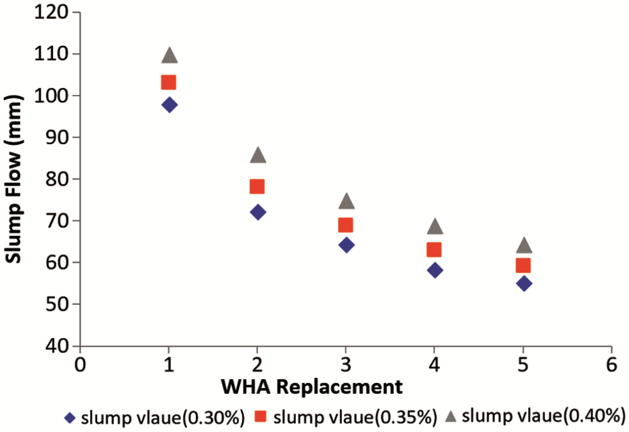


Fig. 6 — Slump value of all samples.

As more WHA is used as a replacement for PC in concrete, it is demonstrated that the workability of green concrete would decrease. This growth in the slump has diminished as a result of WHA's enormous surface area, which absorbs larger amounts of water than fine particles Patidar[25] .An ASTM C1437-compliant slump flow test was performed. In Fig. 6, the slump flow values of cement that contains 10%, 15%, 20%, and

25%, of wheat husk ash as a sustainable partial substitute for cement are depicted. Since WHA's particles are smaller than those of cement, this is likely what contributed to the decrease in slush flow Al-Akhras[26]. As a result, the addition of WHA enhanced the volume % and surface area of the binder. The capacity of the larger surface to absorb greater quantities of water increased the requirement for water and decreased the amount of free water in the combination. There is a greater need for super plasticizers in concrete containing wheat husk ash because of the wheat husk ash's exceptionally tiny particle size, which causes some of the super plasticizers to soak on its surface Ataie[27].

For the new concrete incorporating WHA at the maximum weight percentage of 25% as a cement substitute, the slump values decreased to 59 mm Figueroa[28.]

3.2 Compressive strength

Figure 7 displays the concrete sample findings for compressive strength after 28 days. For samples WHA0, WHA10, WHA15%, WHA20%, and WHA25 %, the compressive strength results were 55.38MPa, 56.45 MPa, 58.84 MPa, 56.66 MPa, and 53.65 MPa, respectively for 0.30 water cement ratio Patidar[29]. Additionally, It has been shown that adding up to 7% of WHA yields favorable results, which may be related to pouring finely dispersed WHA during the pozzolanic reaction of WHA, after which the compressive strength decreases. This behavior is similar to that seen by the author, who found that after 28 days, concrete's compressive strength increased when its WHA content was increased, and replacing cement up to 20% of the original amount Jain[30].

The combination of the cement's hydration product with WHA to produce C-S-H and the filling action of WHA particles are mostly responsible for this improvement in compressive strength. The compressive property of the concretes was significantly improved by increasing the concentration of wheat husk ash. This result is directly connected to the filling effect of wheat husk ash, which increases the binding strength of the cemented paste-aggregate interface Rithuparna[31].

3.3 Water absorption Test

The percentage of water absorption is a measure of the concrete's porosity or permeability after it has hardened and is one of the main elements affecting concrete's durability. The results of the water absorption test for the straightforward concretes including wheat husk ash are shown in Fig. 8 Rolón[32]. The table shows that wheat husk ash-infused concrete absorbs water substantially less than conventional concrete. Figure 8 also demonstrates that as the amount of wheat husk in concrete increases, so does its capacity to absorb water. Wheat husk ash particles can block pores, as was already mentioned, which reduces the permeation of water in concrete Memon[33].

The use of wheat husk ash serves to lessen the concrete's water absorption for a particular amount of concrete.

3.4 Acid resistance test

When exposed to harsh acidic conditions, such as those found in sewer linings, sewage pipes, industrial projects, etc., concrete is vulnerable to acid assault. The acid assault causes the concrete matrix's elements to dissolve and leach. In comparison to high molecular mass acids like stearic, palmitic, and oleic acids, exposure to other acids such as hydrochloric acid (HCl), sulfuric acid (H_2SO_4), acetic acid (CH_3COOH), and nitric acid (HNO_3) has been shown to cause more harm. In the case of reinforced concrete structures, the acid assault does much more harm since the ingested H+ ions will cause a chemical imbalance that will cause the rebars to lose their passivation and the concrete structures to corrode Kumar[34].

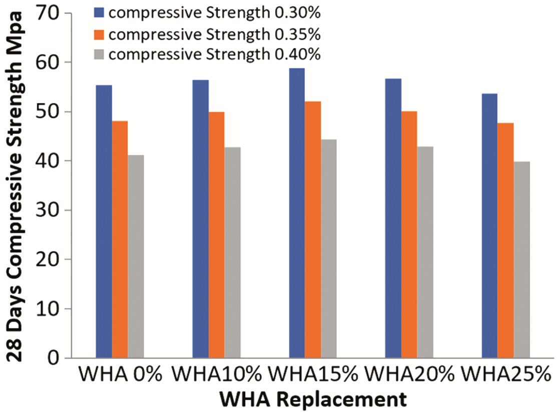


Fig. 7 — Compressive strength at 28 days.

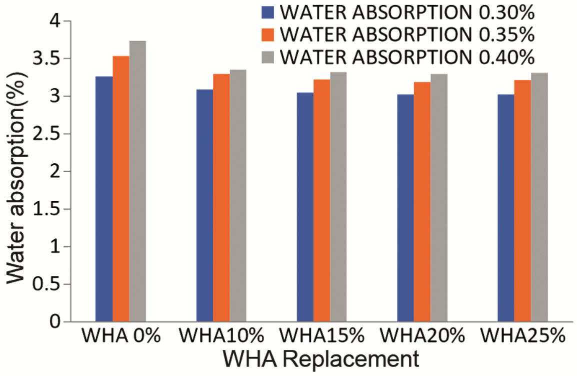


Fig. 8 — Percentage of water absorption.

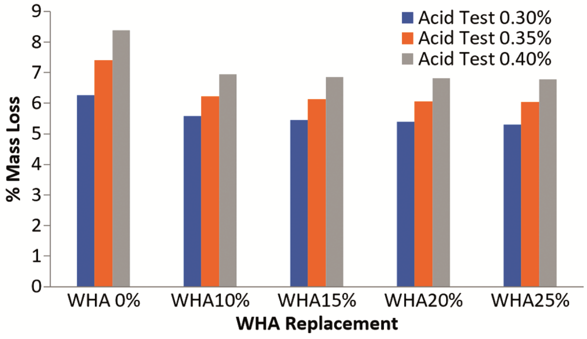


Fig. 9 — Acid resistance.

Damage is frequently quantified in terms of remaining compressive strength, mass loss, and depth of corrosion. In contrast, to cement concrete, and mass loss (%) of various WHA specimens are shown in Fig. 9. For varying amounts of time, these samples were submerged in solutions of acid (5% H_2SO_4) Khan[35].

The sample's remaining compressive strength following acid exposure is referred to as the residual compressive strength. It is important to note that after 28 days of immersion in H_2SO_4 solution, specimens containing WHA25 showed the strongest resistance to acid attack with the least amount of compressive strength loss (10.16%) compared to cement concrete specimens. However, compared to the control/blank mix, weight loss with 30% wheat husk ash is greater. The reason for this is that at larger dosages (25% wheat husk ash), the workability of concrete declines, increasing the need for compaction, resulting in porous Charitha[36].

4 Conclusion

To enhance the physical, mechanical, and micro-structural qualities of eco-friendly concrete, this study analyses the utilization of agricultural waste—wheat husk ash. Overall, it was found by comparing the performance of cement composites made with and without wheat husk ash that the characteristics of cement pastes were improved when wheat husk ash was used in place of cement. Based on test results, it is possible to derive the following conclusions:

a Concrete's workability and density can be reduced by up to 25% by adding WHA.
b Concrete containing WHA has a lower density and workability than the concrete used as a control.
c The findings of the slump value test demonstrate that suitable mixes for sustainable concrete using wheat husk ash need a little more water. The greater surface area of wheat husk ash allows it to absorb more water, resulting in more cohesive mixtures. Additionally, it is seen that WHA concrete mixes are set up more quickly than control ones. Cement pastes because they are more hydrated. Due to the increased synthesis of hydration products, WHA concrete has lesser water absorption and porosity than control concrete.
d Concrete's split tensile, compressive, and flexural strengths all rise with the addition of up to 20% WHA. In general, as curing regimes were increased, all mixtures' compressive strength, splitting tensile strength, and flexural strength properties improved. The strongest mixture was one that included 20% additional cementitious material., As SCM content exceeds 20%, the strength does, however, marginally decline.
e The ash samples included amorphous phases of SiO_2.
f The results of tests for permeability resistance, capillary absorption, and water absorption show that wheat husk ash concrete has higher permeability resistance than conventional concretes. This is because wheat husk ash concrete has a more homogeneous and thick microstructure than reference concrete, as shown by the SEM test.
g Wheat husk ash makes the mixture more particle-rich, which reduces the consistency and workability of freshly set and properly cured concrete. To change the microstructure of concrete and thus reduce permeability, which in turn prevents water from penetrating and causing corrosion, wheat husk ash must be replaced in concrete. By including up to 20% of wheat husk ash, the mechanical properties of concrete samples were improved at all water-cement ratios. This results from the hydration of goods and the pore-filling abilities of ash-based compounds. The features of nanoscale-size particles can be significantly improved when compared to typical grain-size materials with the same chemical makeup.
h It is feasible to make eco-friendly concretes by using WHA for OPC.
i The use of WHA in the manufacturing of concrete offers those materials a new home and reduces the amount of cement in the concrete, which reduces CO_2 emissions (from the manufacture of cement) and sand extraction.

References

1 Prusty J K, Patro S K & Basarkar S S, *Int J Sustain Built Environ*, 5 (2016) 312.
2 Masanja D N, Muya M S & Nyangi P, *Civ Eng J*, 8 (2022) 671.

3 Zaid O, Ahmad J, Siddique M S, Aslam F, Alabduljabbar H & Khedher K M, *Sci Rep*, 11 (2021) 12822.
4 Binici H, Yucegok F, Aksogan O & Kaplan H, *J Mater Civ Eng*, 20 (2008) 478.
5 Eker H & Bascetin A, *Constr Build Mater*, 317 (2022) 126089.
6 Bheel N, Awoyera P, Shar I A, Abbasi S A & Khahro S H, *Case Stud Constr Mater*, 15 (2021) e00729.
7 Qudoos A, Kim H G, Jeon I K & Ryou J S, *Powder Technol*, 352 (2019) 453.
8 Schiavon J Z, Borges P M, Silva S R D & Andrade J J D O, *Materia (Rio J)*, 26 (2022).
9 Cappucci G M, Ruffini V, Barbieri V, Siligardi C & Ferrari A M, *J Clean Prod*, 349 (2022) 131437.
10 Chen H, Chen Q, Xu Y & Lawi A S, *Constr Build Mater*, 316 (2022) 125887.
11 Qudoos A, Ullah Z & Baloch Z, *Adv Mater Sci Eng*, 2019.
12 Chin C S & Nepal B, *Ecol Wisdom Inspired Restor Eng*, 2019 109–120.
13 Naqvi H J, Saeed A, Umair A & Shah F H, *J Pak Inst Chem Eng*, 39 (2011) 51.
14 Cizer Ö, Van Balen K, Elsen J & Van Gemert D, *RILEM Symp Proc*, 2006.
15 Javed M H, Sikandar M A, Ahmad W, Bashir M T, Alrowais R & Wadud M B, *J Build Eng*, 57 (2022) 104850.
16 Liu Y, Zhao X, Li J, Ma D & Han R, *Desalin Water Treat*, 46 (2012) 115.
17 Shinohara Y & Kohyama N, *Ind Health*, 42 (2004) 277.
18 Bheel N, Ali M O A, Kirgiz M S, de Sousa Galdino A G & Kumar A, *J Mater Res Technol*, 13 (2021) 872.
19 Amin M, Zeyad A M, Tayeh B A & Agwa I S, *Constr Build Mater*, 320 (2022) 126233.
20 Bledzki A K, Mamun A A & Volk J, *Compos Part A*, 41 (2010) 480.
21 Bheel N, Awoyera P, Shar I A, Sohu S, Abbasi S A & Krishna Prakash A, *Adv Civ Eng*, (2021) 1.
22 Patidar S & Mahiyar H K, *Int Res J Eng Technol*, 9 (2022).
23 Hameed M A A K, Alzerjawi A K R & Mahdi Z A, *J Phys Conf Ser*, 1973 (2021) 012174.
24 Kiran S R & Gupta V, *Int J Sci Res Dev*, 3 (2015) 311.
25 Patidar A, Longre P & Baradiya V, *Int J Tech Innov Mod Eng Sci*, 4 (2018) 270.
26 Al-Akhras N M & Abu-Alfoul B A, *Cem Concr Res*, 32 (2002) 859.
27 Ataie F F & Riding K A, *J Mater Civ Eng*, 25 (2013) 1703.
28 Figueroa J D C, Hernández Z J E, Véles M J J, Rayas-Duarte P, Martínez-Flores H E & Ponce-García N, *Cereal Chem*, 88 (2011) 12.
29 Patidar A & Chauhan J S, *Adv Concr Constr*, 20 (2025) 509.
30 Jain D, Gupta A, Jain H & Scholar M E, *Int J Sci Res Dev*, 3 (2015) 764.
31 Rithuparna R, Jittin V & Bahurudeen A, *J Clean Prod*, 316 (2021) 128242.
32 Rolón B G & Castañeda P F, *Cleaner Mater*, 2 (2021) 100028.
33 Memon S A, Wahid I, Khan M K, Tanoli M A & Bimaganbetova M, *Sustainability*, 10 (2018) 1322.
34 Kumar A, Gupta R & Sharma P, *Constr Build Mater*, 272 (2021) 121846.
35 Khan K, Ishfaq M, Amin M N, Shahzada K, Wahab N & Faraz M I, *Materials*, 15 (2022) 3177.
36 Charitha V, Athira V S, Jittin V, Bahurudeen A & Nanthagopalan P, *Constr Build Mater*, 285 (2021) 122851.