

The Role Of Rice Husk Ash In Sustainable And Eco-Conscious Cement Production

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Literature Review

Type of Rice Husk Ash

Concrete, being the second most commonly utilized construction material globally, follows water in terms of frequency of use. A relatively large quantity of materials is utilized as a result of the yearly production of billions of metric tons of concrete. The concrete industry, as indicated by data, is the sector that consumes the greatest number of natural resources. The production of Ordinary Portland Cement (OPC), which is essential for the creation of concrete and significantly increases the amount of carbon dioxide released as a consequence of human activity, has an impact on the occurrence of global warming and depletes these natural resources. Moreover, the projected exponential rise in the demand for cement and concrete in the forthcoming years is predicted to result in increased carbon dioxide emissions stemming from OPC manufacturing. Therefore, it is imperative for the concrete industry to explore strategies aimed at reducing or substituting the natural resources utilized in concrete, specifically OPC. Over time, numerous approaches have been investigated, including the partial or complete replacement of OPC, the incorporation of waste materials as aggregate in concrete, and the utilization of wastewater. One of the primary methods for reducing the carbon content of concrete is to partially substitute OPC with other cementitious constituents. Most supplementary cementitious materials (SCMs) are waste materials possessing pozzolanic and hydraulic properties. Throughout history, there haven't been any SCMs used as partial alternatives like slag, fly ash, metakaolin, Rice husk ash (RHA) and silica fume. The utilization of SCMs in concrete also provides a means of managing these waste materials, thereby avoiding any potential environmental harm arising from their disposal. Different SCMs exhibit distinct influences on the rehabilitated and toughened characteristics of concrete, and it has been proposed that the selection of the appropriate type and level of OPC replacement represents the optimal approach for incorporating these waste materials into concrete. RHA, a kind of SCM derived from agricultural waste, was not discovered to improve the mechanical and strength properties of concrete. Due to its high responsiveness and silica content, RHA is a favoured SCM in comparison to fly ash and silica fume. The notable concentration of amorphous silica and extensive surface area of RHA contribute to its significant reactivity.

The construction industry has recently been quite interested in RHA, which provides a sustainable alternative to traditional building materials. RHA, a consequence of rice milling, deviates from conventional waste management methods and finds new applications in the search for ecologically

friendly building materials. Understanding RHA's origin and makeup is the first step in turning it from a byproduct that is thrown away to a building material that might revolutionise the industry. Since rice is a staple meal for a sizable section of the world's population, rice husks are produced throughout the milling process. These rice husks, which are typically disposed of as garbage, are burned under regulated conditions to produce RHA. The resultant mixture, which consists of amorphous silica, carbon, unburned rice husk, and trace elements, is what gives RHA its distinctive qualities and makes it an appealing contender for green building. The environmental sustainability of RHA is one of the main elements influencing interest in it. By using a waste product that would otherwise add to environmental problems, RHA offers an appealing alternative in an era where the ecological effect of construction materials is being closely examined. Utilising RHA adheres to the principles of a circular economy since it not only minimises waste but also lowers the need for conventional raw materials. RHA is positioned as a material that, in addition to meeting technical building requirements, supports the overriding objective of sustainable development as a result of its environmental consciousness. Beyond its benefits for the environment, RHA has advantages over conventional building materials, notably cement and concrete. The manufacture of cement is notorious for using a lot of energy and leaving a big carbon footprint. The utilization of RHA as an extra cementitious substance can lessen the need for cement and the overall environmental effect of construction projects. RHA inclusion also improves the durability and workability of concrete. It provides a more durable and long-lasting building material by reducing corrosion and cracking. The lightweight properties of RHA-infused materials also have an impact on structural design, providing the potential to build buildings that are more effective and sustainable. The growing understanding of RHA's potential in building is reflected in the landscape of global research. Around the world, researchers, engineers, and architects are actively investigating a range of RHA-related topics, including production processes, material characteristics, and structural performance. This increase in research reflects a general understanding of the value of sustainable building techniques and the part that RHA can play in accomplishing these goals. The thorough examination of RHA in the literature is evidence of its expanding significance as a topic for research and application.

Grey RHA and White RHA represent the primary manifestations of RHA, although additional variants exist as well. W-RHA is created by controlled combustion at low temperatures, producing finer, whiter ash with a higher concentration of amorphous silica. This kind is highly sought-after because of its strong pozzolanic reactivity, which makes it perfect for uses like high-performance concrete. G-RHA, on the additional point, is a creation of uncontrolled fiery or incineration that frequently occurs at greater temperatures and may have a larger carbon content. G-RHA is used in construction, especially in less demanding situations, despite its less polished character. RHA can also be classified as crystalline or amorphous, depending on the combustion circumstances that encourage the majority of either structure, going beyond this binary categorization. While crystalline RHA is being researched for its unique behaviour in building materials, amorphous RHA is well recognised for its high reactivity and contribution to the strength and toughness of concrete. In totalling, surface-modified RHA is subjected to physical or chemical processes to improve qualities like dispersion and adhesion, finding use in composite materials and polymer matrices. The many RHA varieties provide a sustainable and

adaptable option for building materials by meeting a range of construction demands. The idea of using the RHA as a traditional binder in concrete was emphasised by (Mounika et al., 2022) study based on a thorough review. There will also be a study of the chemical, physical and mechanical characteristics of many concretes with RHA. In a nutshell, it was discovered through the examination of the literature that RHA-produced concrete is less workable than ordinary concrete. Because RHA has a lower density than traditional concrete, it may be employed in a variety of construction projects. Concrete that has been combined with RHA has increased mechanical qualities such as flexural strength, compressive strength and splitting tensile strength for smaller replacement (by up to 30%). When compared to a typical mix, concrete containing RHA demonstrated greater bond strength, decreased chloride diffusion, increased resistance to sulphate and chemical attacks, and decreased efflorescence.

(Taiwo *et al.*, 2022) employed Quarry dust (QD) and RHA to build a sustainable composite. To create unconventional composite samples, the researchers utilized varying proportions of RHA and QD to partially substitute cement and river sand, respectively. The preparation of conservative compound examples, however, used cement and river sand. Following that, the formed mixtures underwent different curing durations, and the resulting block samples were assessed for compressive strength using a Worldwide challenging apparatus. The enhanced compressive power of the specimens and the observed recovery time were shown to be significantly correlated. Furthermore, it was demonstrated that non-traditional composite samples had a lower bulk density than their conventional counterparts. While the unconventional composite samples displayed delamination on their outside surfaces, the typical composite samples failed with localised shear surfaces and many fissures. The findings of this study indicate that it is possible to produce sustainable construction materials by partially substituting QD and RHA for cement and river sand, respectively. (Chen *et al.*, 2021) The key features of RHA and its diverse uses in the building and construction industry, environmental preservation, and particularly geotechnical engineering have been outlined. A thorough analysis of the RHA-soil mixture's literature was conducted in order to fill in the information gaps about the behaviour of the RHA-soil combination with regard to durability, mechanical qualities, environmental effect, and internal mechanism. The results showed that adding RHA may significantly improve the soil's compressive strength, shear strength, and CBR (California Bearing Ratio) value, offering benefits to the economy and the environment. Additionally, it can significantly enhance the soil's resistance to shrinkage cracking. Generally speaking, the broad usage of RHA as a fractional additional for cement/lime in geotechnical engineering shows promise since it may support energy saving, lower carbon emissions, and sustainable development. The development of more active RHA, the micro mechanism of RHA-soil, as well as the robustness, degradation mechanism, and environmental impact of RHA treatment on soil mixtures in complex situations all require more study. (Das *et al.*, 2020) We endeavoured to explore the physical, organic, and microstructural attributes of the material by employing an extensive array of sophisticated analytical techniques, including FTIR, XRF, XRD, PSA, and FESEM. Additionally, we performed an experimental plan to investigate the conduct of geopolymers derived from fly ash and blast furnace slag, incorporating different quantities of RHA. The investigation revealed that both the workability and compressive strength of geopolymers

concrete decline with an increase in the proportion of RHA. Nevertheless, geopolymers containing 10 per cent RHA demonstrated a compressive strength of 25 MPa, a level that is regularly employed in numerous construction ventures. This finding broadens the potential utilization of RHA for the production of environmentally friendly binders through the process of geopolymerization. (Jittin *et al.*, 2020) The operation of RHA in the more ecologically friendly manufacture of building materials such as bricks, blended cement and alkali-activated binder was thoroughly investigated. The application of RHA in various building practices, such as earth stabilization and subgrade behaviour, was also deliberated. Furthermore, scientific observations regarding the chemical, physical, and mineralogical characteristics of RHA, which are vital to the engineering characteristics of RHA-blend building products, were provided. When incorporated at a rate ranging from 10 to 20 per cent in different construction sectors, RHA has been acknowledged to improve the quick and lasting engineering attributes of building materials. Consequently, RHA presents an economical and energy-efficient alternative for building manufacturing. Moreover, proposed techniques and guidelines for the utilization of RHA in the building sector's cleaner production were suggested. (Joel, 2020) investigated how the chemical composition of fly ash and RHA, which were used as partial replacements for concrete, affected the compressive strength of the material. Graphs, figures and tabular data were used as study tools to examine the different chemical mechanisms of fly ash and RHA. It was discovered that the level of numerous minor components, such as "sodium oxide (Na_2O)", "titanium oxide (TiO_2)", and "phosphorus pentoxide (P_2O_5)", was usually insignificant or not recorded in the finished product, depending on how the coal or rice husk was first processed. According to data analysis on the compressive strength of concrete after incremental percentage additions of fly ash and RHA, respectively, the ideal replacement percentage for fly ash and RHA to partially replace cement in order to achieve a high compressive strength is 30 percentage for fly ash and 7.5 percentage for RHA.

Table 2.1: Review of types of RHA

Citation and Author	Aim	Method Used	Limitations
Taiwo et al., 2022	To create sustainable composite materials	Used Quarry dust (QD) and RHA Varying proportions of RHA and QD to partially substitute cement and river sand, Compressive strength testing using a challenging apparatus	Delamination observed in non-traditional composite samples, Limited details on the curing process

Chen et al., 2021	To outline the characteristics and uses of RHA	Literature analysis of RHA-soil mixture, Evaluation of RHA's impact on soil properties	Lack of in-depth analysis of the environmental effects of RHA. Complex situations require further study.
Das et al., 2020	To explore geopolymer concrete with RHA	Extensive analytical techniques (FTIR, XRF, XRD, PSA, FESEM), Experimental plan with varying amounts of RHA	Decline in workability and compressive strength with higher RHA content, Limited explanation of specific findings
Jittin et al., 2020	To investigate RHA's application in construction	Thorough investigation of RHA in various construction practices, Assessment of RHA's properties and its impact on engineering characteristics	No specific details on the construction practices studied; suggested techniques and guidelines need elaboration
Joel, 2020	To examine the chemical composition of ash in concrete	Analysis of chemical components of fly ash and RHA, Evaluation of their impact on compressive strength	Limited explanation of the methodology, General recommendations without specific details

2.1 Amorphous Rice Husk Ash

The unique arrangement of shapeless ash derived from rice husk, known as amorphous RHA (RHA), sets itself apart by containing a notable amount of shapeless silica. This achievement is the result of carefully coordinated combustion procedures. When rice husks are carefully burned at relatively low temperatures, a large portion of non-crystalline, disordered silica structures are kept in the ash that is produced. The RHA is a desirable material for a number of applications, notably in the construction sector, thanks to its special qualities brought about by its amorphous form. RHA has a higher level of reactivity than other materials, which is an essential quality for pozzolanic materials. This is a result of its amorphous structure. Upon being added to concrete mixes, amorphous RHA interacts with the calcium hydroxide produced during the hydration of cement. Additional Calcium Silicate Hydrate gel, which considerably increases the strength and durability of concrete, is produced as a result of this

chemical reaction. The development of the motorized and toughness possessions of concrete buildings requires the incorporation of amorphous RHA. Amorphous RHA has the noticeable benefit of lowering the heat of hydration in concrete. In large-scale construction projects, where excessive heat generation during the curing process can cause thermal cracking and jeopardise the structural integrity of the building, this is especially important. This problem is lessened by amorphous RHA's controlled combustion process, which encourages a more regulated release of heat during hydration. The usage of amorphous RHA is not just for conventional concrete applications. It has demonstrated success in improving the qualities of other building materials, such as mortars, grouts, and even geopolymers. Amorphous RHA's small particle size and large surface area make these materials easier to deal with and more cohesive.

Beyond its technological advantages, amorphous RHA adheres to the fundamentals of sustainable building. Amorphous RHA helps to lessen environmental effects and waste disposal difficulties by recycling rice husk waste, a result of agricultural activities. Amorphous RHA manufacture is also more energy-efficient than that of other conventional building materials because of the controlled combustion process. (Alomayri *et al.*, 2021) Blast furnace slag (BFS) was used as the main precursor to create AACs. Variable amounts of amorphous raw RHA (RRHA) were used to partially replace BFS. The RRHA content and the curing circumstances were taken into account while evaluating how well AACs performed. Both ambient temperature curing and heat curing at 60 °C for 24 hours, followed by ambient temperature curing, were used as curing techniques. The study's conclusions show that using RRHA in lieu of BFS at a rate of 10% improves mechanical and durability performance and is thus the most ideal. The study also discovered that AACs function better when heat curing for 24 hours before curing at ambient temperature.

(Dhaneswara *et al.*, 2020) Created RHA by burning rice husks for five hours at a temperature of 700°C in an electric furnace. In order to perform the reflux procedure on the RHA, sodium hydroxide resolutions at absorptions of 1.25 and 2.5 10⁻³ M were used. To produce silica gel, the acidification process required the use of hydrochloric acid (HCl) at a concentration of 1 M and acetic acid (CH₃COOH) at a concentration of 1 M. Then, heating the silica gel at 120°C for 12 hours led to the formation of silica. Various techniques such as energy-dispersive X-ray analysis, Fourier-transform infrared spectroscopy, the Brunauer-, X-ray diffraction and Emmet-Teller techniques were employed to characterize the silica. The findings indicated that silica obtained through HCl acidification exhibited a higher level of purity compared to that obtained through CH₃COOH acidification. The enhanced purity of silica was a consequence of the higher concentration of the sodium hydroxide solution. Through X-ray diffraction examination, the amorphous character of the silica generated from RHA was established, and Fourier-transform infrared spectrometry demonstrated the presence of bending and stretching vibrations relevant to the Si-O and Si-O-Si bonds. It was discovered that after the silica was subjected to HCl acidification, the material had an average pore diameter of 9 nm, a total pore volume of 0.54 cc/g, and a surface area of 236 m²/g. (Nayak *et al.*, 2023) the present investigation aimed to enhance the conditions in the process of reclaiming RHA, an agricultural byproduct that contains amorphous silica and can be utilized in the production of silicon compounds. In order to optimize the process, a combination of artificial intelligence-based and multi-objective

genetic algorithms (MOGA), response surface methodology (RSM) and back-propagation artificial neural networks (BPANN) were employed. The variables examined in this investigation encompassed both the temperature and period of the calcination technique, as well as the leaching process. X-ray diffraction analysis and an evaluation of RHA recovery were used to determine the effects of these process parameters on the volume and percentage of silica that crystallises in RHA. The hybrid RSM-BPANN-MOGA model integrated a fitness function developed using regression equations derived from RSM, while forecasted data from BPANN served as the initial score. The most efficient project fact was identified by means of the TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) executive method, which was selected from a set of optimized alternatives created as Pareto fronts. The optimal process parameters were determined to be a leaching temperature of 75°C, a leaching duration of 1 hour, a calcination temperature of 550°C, and a calcination period of 2 hours. The enhanced typical was authenticated against observed data and originated to be well-fitted, with total mistakes for per cent crystallinity, per cent RHA recovery, and per cent volume of silica, respectively, of 7.42%, 2.03%, and 4.26%. Furthermore, a comparison was made between non-leached RHA and optimized RHA through various material characterization methods. This study showcased the comparative advantage of the enhanced action settings in terms of reduced crystallinity, higher purity and improved particle shape.

Table 2.2: Review of Amorphous RHA

Citation and Author	Aim	Method Used	Limitations
Alomayri et al., 2021	To evaluate the performance of AACs with amorphous raw RHA (RRHA)	Use of blast furnace slag (BFS) as the main precursor for AACs, Partial replacement of BFS with RRHA, Evaluation of mechanical and durability performance, Variation of RRHA content and curing conditions	Limited details on specific mechanical and durability parameters studied, Lack of information on long-term performance

Dhaneswara et al., 2020	To produce and characterize silica from RHA (RHA)	Burning rice husks to create RHA, Reflux procedure using sodium hydroxide solutions, Acidification with HCl and CH ₃ COOH, Characterization using numerous methods such as FTIR, BET, XRD, and XRF	Focus on silica production, not direct application; limited information on specific applications of the obtained silica.
Nayak et al., 2023	To optimize the process of reclaiming RHA for the production of silicon compounds	Use of artificial intelligence-based and multi-objective genetic algorithm (MOGA), Response surface methodology (RSM) and back-propagation artificial neural networks (BPANN), Examination of calcination and leaching process variables, Material characterization using XRD	Complex modelling approach may have limitations in accuracy, Lack of detailed information on the potential applications of the optimized RHA

2.1.1 As a replacement material for cement

Minimal improvement is being made in the advancement of environmentally hostile and unsustainable construction methods through the utilization of amorphous RHA (RHA) as a substitute for cement in building materials. Concrete, an insignificant constituent in the production of cement, is widely unrecognized for its efficacy in terms of energy utilization and the release of carbon dioxide. A feasible alternative that not only mitigates the environmental impact but also enhances the overall functionality of building materials is the regulated incineration of rice husks for the generation of amorphous RHA. The distinctive attributes of amorphous RHA render it an attractive substitute for cement across various applications. Its amorphous state, achieved through meticulous regulation of combustion at lower temperatures, enhances reactivity, particularly in pozzolanic reactions. Amorphous RHA (RHA), when used as a partial substitute for cement in concrete mixes, interacts with calcium hydroxide during the process of hydration to produce extra calcium silicate hydrate (C-S-H) gel. The finished concrete buildings benefit from the strength and longevity of this additional gel. The environmental problems caused by the production of traditional cement can be resolved by using amorphous RHA instead. The cement sector is a primary target for sustainability measures due to its

well-known considerable contribution to global carbon dioxide emissions. As a result of the agricultural sector, amorphous RHA is a sustainable option that reuses a waste product, particularly rice husks. In addition to converting this waste into a useful building material, the controlled combustion method does so with less environmental impact than conventional cement manufacturing.

The use of amorphous RHA in place of cement has environmental advantages beyond a decrease in carbon emissions. Because cement is a resource-intensive material, its demand may decline as a consequence of the addition of RHA to existing mixtures. This decrease helps to reduce the energy needed to produce cement while also protecting natural resources. As a result, the use of amorphous RHA addresses both resource efficiency and environmental impact, which is in line with the larger objectives of sustainable construction practices. In addition to its advantages for the environment, using unstructured RHA as a cement supernumerary enhances the properties of concrete. Better workability and durability of concrete constructions are facilitated by the increased reactivity of amorphous RHA. Amorphous RHA's smaller particle size also makes it easier for it to disperse effectively in the concrete matrix, creating a more uniform mixture and lowering the chance of segregation. The impact of hydration on the heat of concrete is one of the crucial factors to take into account when using amorphous RHA as a cement substitute. Amorphous RHA is produced by the controlled combustion process, and when added to concrete mixtures, it reduces the heat produced during the hydration of cement. Large-scale building projects frequently worry about excessive heat generation since it might cause thermal cracking and jeopardise the concrete's structural integrity. Amorphous RHA is a useful component in projects where thermal control is essential because of its capacity to control the heat of hydration. (Adnan *et al.*, 2022) tried to evaluate how well RHA achieved as a spare for sure cement. In terms of compressive, flexural, and tensile strength, it was extremely unlikely to deduce from the works that concrete containing 5 per cent to 15 per cent of RHA performed comparably to regular concrete. Chemical and mechanical qualities, as well as various incineration or combustion processes used to create RHA, are among the attributes that will be assessed. (Muthukrishnan *et al.*, 2019) The thermal treatment of iRHA (TRHA) was investigated in order to produce ash with better corporeal and biochemical possessions. This ash could potentially be used to decrease the amount of cement in filling by 20 per cent (by weight). Using unstructured RHA as a cement supernumerary improves the characteristics of concrete and its environmental benefits.

Specifically, RHB replaced 10% and 40% of iRHA by weight, resulting in improved qualities. A comparison was made between the mortar containing RHA and the control mortar, both of which were prepared under carefully monitored laboratory conditions. Investigational consequences revealed that the addition of TRHA amplified the strength of the mortar by 20 per cent and 34 per cent compared to mortar containing only iRHA at both early and mature ages. Despite exhibiting equivalent strength development to the control, the TRHA mortar demonstrated reduced autogenous shrinkage and water permeability, indicating enhanced durability as a construction material. Moreover, the incorporation of RHB, substituting 40% of iRHA, enhanced the long-term compressive strength and water tightness by 17% and 23%, respectively, when compared to iRHA alone. Additionally, when mixed with RHB, the mortar's watertightness showed a 12% increase above the norm. The carbon content of RHB particles

and its reservoir impact helped to reduce autogenous shrinkage during the course of the six-week observation period. LabRHA demonstrated the greatest increase in water-tightness among the examined additives, with a 23% decrease in capillary absorption relative to the norm. These findings imply that industrial-grade RHA has the potential to be used as an addition to cementitious building resources, reducing the demand for landfilling and carbon sequestration in constructed surroundings.

Table 2.3: review of amorphous RHA as a replacement material for cement

Citation and Author	Aim	Method Used	Limitations
Adnan et al., 2022	To evaluate the performance of RHA as a substitute for cement in concrete	Assessment of compressive, flexural, and tensile strength of concrete with varying percentages (5% to 15%) of RHA, Evaluation of chemical and mechanical qualities, Examination of different incineration or combustion processes used for RHA	Lack of specific details on the range of chemical and mechanical qualities assessed, Limited information on the long-term performance of concrete
Muthukrishnan et al., 2019	To investigate the thermal treatment of industrial-grade RHA (iRHA) for improved concrete properties	Study of the thermal treatment of iRHA (TRHA), Replacement of 10% and 40% of iRHA by weight with reactive rice husk biochar (RHB), Comparison between mortar containing TRHA and control mortar, Examination of various properties under laboratory conditions	Specific details on the incineration or combustion processes used for iRHA are not provided; limited information on the specific environmental benefits of RHA

2.1.2 As a mineral admixture

The exceptional mineral additive recognized as amorphous RHA enhances the efficacy, sustainability, and toughness of construction materials. RHA, a byproduct of rice milling that is abundant in amorphous silica and generates finely fragmented particles through controlled combustion, is an excellent choice for mineral admixtures in a diverse range of applications. The main function of this

mineral additive lies in its pozzolanic activity. When added to concrete mixtures, the pozzolanic components interact with the calcium hydroxide produced during cement hydration. The augmented amorphous silica component of amorphous RHA heightens its reactivity, foremost to the development of a greater amount of calcium silicate hydrate gel. This additional gel aids in densifying the concrete matrix, thereby enhancing both its strength and longevity. Essential in minimizing the demand for cement and reducing the carbon footprint of conventional concrete manufacturing, amorphous RHA, as a mineral additive, offers numerous significant advantages when added to mineral admixtures. Firstly, it enhances the workability and cohesion of concrete, facilitating the construction process. The minute atom size and extensive superficial part of amorphous RHA result in the production of a more uniform and compact structure, promoting effective dispersion within the concrete mix. This aids in enhancing resistance to typical problems with concrete buildings, such as segregation and bleeding. Reduced heat of hydration is a key additional advantage. The controlled combustion process of amorphous RHA aids in controlling the heat produced during cement hydration. Thermal cracking in concrete can result from excessive heat production, especially in large constructions. Construction projects can reduce this danger by adding amorphous RHA, assuring the long-term integrity of the concrete structures.

It is impossible to exaggerate the benefits of employing amorphous RHA as a mineral additive for the environment. Amorphous RHA helps reduce waste and lessens the environmental effect of trash disposal by recycling a waste product from the agricultural sector, specifically rice husks. Additionally, its utilisation conforms to the tenets of sustainable building by lowering the need for conventional raw materials in concrete. Amorphous RHA is a mineral additive that has uses other than in conventional concrete. High-performance mortars, grouts, and concrete are all made using it. Amorphous RHA's adaptability enables it to aid in the creation of cutting-edge building materials. Amorphous RHA has demonstrated potential in geopolymer technology, which uses aluminosilicate materials to substitute Portland cement, because of its pozzolanic reactivity and capacity to contribute to the creation of geopolymers. In order to use amorphous RHA as a mineral admixture, it is important to optimise the mix proportions, comprehend how it interacts with other concrete additives, and assess long-term durability. To make sure that the inclusion of amorphous RHA in building materials produces dependable and long-lasting results, researchers and practitioners are still investigating these issues. (Jindal *et al.*, 2020) RHA-based GPC, equipped with changing sizes of RHA and ultra-fine slag (UFS), was triggered using a predetermined amount of an alkaline solution containing sodium silicate and sodium hydroxide. The curative procedure was carried out at a temperature of 27 degrees Celsius. The study focused on assessing the durability, compressive strength, absorption and water permeability of GPC. Investigations were conducted to determine how various variables may affect the penetrability and water preoccupation of geopolymer concrete. The amount of ultrafine slag, the amount of curing time, and the presence of RHA were among these variables. The results showed that the long-lasting properties of geopolymer concrete based on RHA were significantly improved by the addition of ultra-fine slag. Additionally, using ultra-fine slag helped to condense the GPC specimens. After the data was analysed, it became clear that adding more ultra-fine slag to the RHA-based geopolymer concrete greatly improved its mechanical qualities.

(Gupta *et al.*, 2022) centred on assessing how RHA, silica fume, and powdered ground blast furnace slag affected the motorized characteristics of performance-founded concrete. The subsequent presentation showcased the outcomes of this study. The compressive strength evaluations were conducted on performance-based concrete samples, which incorporated varying proportions of distinct mineral admixtures after 7, 14, and 28 days of curing. The assessments were completed subsequent to restoration under conditions of 20 degrees Celsius and 65 per cent comparative humidity. An entire 90 blocks were cast for comparative testing of several concrete compositions to determine their compressive strength. The examination outcomes uncovered that the compressive strength of the mixture increased by 6.62%, likened to the switch combination at 28 days, and the optimal percentage of RHA in the mixture was determined. Additionally, the mix denoted as (C80SF20) exhibited the optimum percentage of silica fume, leading to a 13.4% enhancement in compressive strength. Similarly, the mix labelled as possessed the highest proportion of GGBFS, resulting in a 6.81% elevation in compressive strength.

Table 2.4: Review of Amorphous RHA as a mineral admixture

Citation and Author	Aim	Method Used	Limitations
Jindal et al., 2020	To assess the properties of geopolymer concrete based on ultra-fine slag (UFS) and RHA	Geopolymer tangible triggered with an alkaline solution containing sodium silicate and sodium hydroxide, Assessment of durability, compressive strength, absorption, and water permeability, Examination of variables such as ultra-fine slag amount, curing time, and presence of RHA.	Lack of specific details on the range of variables and their individual effects, Limited information on the long-term performance of geopolymer concrete
Gupta et al., 2022	To evaluate the impact of RHA, silica fume, and coarse blast furnace slag on the motorized characteristics of performance-based concrete	Compressive strength evaluations on concrete samples with varying proportions of inorganic commixtures, Curing at 20 degrees Celsius and 65% humidity, Comparative testing of 90 blocks for compressive strength	Specific details on the individual contributions of RHA, silica fume, and blast furnace slag are not provided; limited information on other mechanical properties of the concrete beyond compressive strength

2.1.3 As a filler in concrete

A sustainable alternative that enhances the characteristics of concrete and contributes to environmental preservation is amorphous RHA. RHA, which contains a significant quantity of shapeless silica and is derived from the milling of rice, is an excellent choice as a filler in concrete mixtures due to its controlled combustion process and the production of finely divided particles. The primary function of amorphous RHA as a plaster is to upsurge the stuffing thickness of the concrete combination. Its small particle size and high superficial part enable it to fill the gaps between larger cement and aggregate particles. This improved packing leads to more efficient utilization of the available space in the concrete matrix, resulting in reduced porosity and increased overall density of the material. Consequently, incorporating amorphous RHA as a filler contributes to the enhancement of the concrete's strength and durability. Additionally, concerns regarding the environmental impact of concrete production can be addressed through the utilization of amorphous RHA as a filler. Traditional concrete production relies heavily on the consumption of natural resources such as cement and aggregates, which exert a significant environmental burden. By replacing some of these conventional elements with amorphous RHA, a byproduct of the agricultural sector, waste is minimized while aligning with the principles of sustainable construction.

Amorphous RHA also functions as a pozzolanic filler, augmenting the reactivity of the concrete mixture. Through its interaction with calcium hydroxide generated during cement hydration, amorphous RHA facilitates the creation of extra calcium silicate hydrate. This supplementary gel reinforces the concrete and enhances its resistance against cracking, thereby improving its long-term performance. Amorphous RHA's pozzolanic activity as a filler works in conjunction with the concrete's overall hydration process to produce a stronger and more resilient material. Moreover, the smaller particle size of amorphous RHA enhances the workability of the concrete mixture. This improved workability simplifies the placement and compaction processes during construction, thereby enhancing the effectiveness of the construction process. The filler action of amorphous RHA ensures a more uniform dispersion within the concrete matrix, reducing the risk of segregation and ensuring consistent qualities throughout the entire structure. However, the utilization of amorphous RHA as a filler in concrete presents challenges and concerns related to optimizing mix proportions, addressing potential variations in setting time, and comprehending its overall impact on the material's performance. Researchers and professionals are currently investigating these issues to ensure that the usage of amorphous RHA as a filler results in concrete that meets the necessary criteria for strength, durability, and workability. (Kang *et al.*, 2019) enhanced the mechanical qualities of ultra-high-performance concrete (UHPC) without the use of heat by employing a responsive filler derived from RHA. By replacing the inert quartz filler with the sensitive RHA filler in this exact method, the formless silica content is augmented, though the corporal possessions of the micrometre-sized quartz grout are conserved. Extensive hydration procedures and effective internal curing are made possible by RHA's high absorbency. Experimental results obtained after 91 days under ambient conditions demonstrated a remarkable strength of approximately 200 MPa. This accomplishment was made possible by the pozzolanic reaction, which was facilitated by the introduction of additional water and

the provision of amorphous silica by the reactive and porous fillers, respectively. Capillary pores' volume is reduced as a result. The study's answers inspired the use of agricultural waste materials for the creation of reactive RHA-based building materials. (Liu *et al.*, 2022) proposed that the workability and compressive strength of concrete be assessed through an analysis of the consequences of substituting a portion of cement with unground RHA. X-ray diffraction was also used to study the hydration byproducts in the blended cement paste. Based on the effect of RHA on the hydration reaction of cement paste, an extra relation perfect and a compressive strength forecast perfect were shaped. The models were evaluated using a variety of statistical indicators. The results showed that adding RHA to fresh cement negatively impacts its workability, whereas adding RHA at a 20% concentration results in the best mechanical properties of cement. The recognized guess model has been shown to correctly anticipate the results of the trials.

(Costa *et al.*, 2021) The impact of adding crystalline and amorphous silica on geopolymers' architectures was investigated. Metakaolin was used as the precursor, with or without the addition of up to 15% of the weight of a source of amorphous or crystalline silica. The Modified Chapelle test and Thermal analysis were used to gauge the raw materials' reactivity. Transmission electron microscopy, Rietveld refinement, and X-ray diffraction with Infrared spectroscopy were used to inspect the geopolymers (TEM). Although it was discovered that pulverized quartz sand is not a pozzolanic substance, it is highly unlikely that metakaolin and RHA will display significant pozzolanic properties. According to TEM analysis, the pure geopolymer made from metakaolin created an amorphous binder called N-A-S-H gel. The amount of the Si-O-Si bond in the geopolymer binder increased as a result of the addition of reactive RHA. However, the projected formless gratified of the geopolymers was reduced as a result of the crushed quartz sand. However, the samples' similar compressive strengths showed that the chemical reactivities of the raw resources had no influence on the geopolymerization process with the addition of 15 wt.% silica. In these conditions, it's likely that some of the RHA won't respond. The unreacted amorphous silica and quartz particles, however, have a filling effect that influences the geopolymer's properties.

Table 2.5: Review of Amorphous RHA as a filler in concrete

Citation and Author	Aim	Method Used	Limitations
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Kang et al., 2019	To enhance the mechanical qualities of ultra-high-performance concrete (UHPC) using responsive filler derived from RHA	Replacement of inert quartz filler with responsive RHA filler in UHPC, Utilization of RHA's high absorbency for wide hydration process and effective internal curing, Experimental testing for strength after 91 days under ambient conditions	Limited information on specific mechanical properties beyond strength, Lack of details on the long-term performance of the enhanced UHPC
Liu et al., 2022	To assess the workability and compressive strength of concrete with substituted unground RHA in cement	Analysis of the functionality and strength in compression of concrete with various replacement rates for unground RHA, X-ray diffraction for studying hydration byproducts, creation of a model to predict the compressive strength and an additional ratio typical	Limited information on other concrete properties affected by RHA. The impact of RHA on workability and compressive strength was addressed but not on other aspects.
Costa et al., 2021	To investigate the impact of adding crystalline and amorphous silica on geopolymers' architectures	Use of metakaolin as a precursor with or without up to 15% weight of amorphous or crystalline silica, Modified Chapelle test and Thermal analysis to gauge raw materials' reactivity, TEM, XRD, and Infrared spectroscopy for inspecting geopolymers	Limited information on the long-term performance of geopolymers with added silica, Possible unreacted portions of RHA affecting results

2.1.4 As aggregate in concrete

The investigation of the use of amorphous RHA as a constituent in concrete is an innovative and

ecologically conscious approach that offers distinctive advantages with regard to its impact on the environment, the characteristics of the material, and the overall efficacy. RHA, a byproduct of the milling of rice, has particular qualities, such as a high concentration of amorphous silica, which makes it an excellent choice for use as an aggregate in concrete mixes. The capacity of amorphous RHA to lighten the total weight of concrete is one of the main advantages of utilising it as an aggregate. RHA's reduced weight makes it possible to create lightweight concrete, which has benefits in a variety of building applications. Concrete that is lighter than average provides advantages, including better insulating qualities, less dead load on buildings, and easier handling during construction. RHA's pozzolanic reactivity is further influenced by its amorphous form. When used as an aggregate, the amorphous silica in RHA mixes with the calcium hydroxide formed during cement hydration to produce additional calcium silicate hydrate gel. Because of this response, the concrete is stronger and more resilient to flexural and compressive pressures. Amorphous RHA's pozzolanic activity as an aggregate enhances concrete's overall performance and makes for a more durable and strong building material. The use of amorphous RHA as an aggregate in concrete is a sustainable way to make use of agricultural waste. Reusing rice husks, which would otherwise be disposed of as garbage, lessens the environmental effect of their disposal. This addresses issues pertaining to resource depletion and waste management and is consistent with the ideas of the circular economy and sustainable construction methods. The carbon footprint of concrete is decreased by using amorphous RHA as an aggregate. Natural aggregate extraction and processing are energy-intensive procedures used in traditional concrete manufacture. The environmental effect associated with the extraction and transportation of natural aggregates is reduced by replacing a part of these aggregates with amorphous RHA.

(Liu *et al.*, 2022) researched and examined the effects of RHA when a portion of Portland cement is replaced on the microstructure and mechanical characteristics of recycled aggregate concrete (RAC). Various tests were performed on specimens with different RHA and spare ratio contents for the coarse aggregate of the castoff concrete. The integration of RHA led to a boost in compressive strength but had a damaging effect on workability and splitting tensile strength. Moreover, the pozzolanic response device of RHA atoms was hypothesized following an analysis of the cement adhesive's microstructure using mercury intrusion porosimetry (MIP), scanning electron microscopy (SEM) and X-ray diffractometry (XRD). The findings demonstrated that the pozzolanic act of RHA particles involves the absorption of "calcium hydroxide (CH)" generated throughout cement hydration, resulting in an elevated concentration of "calcium silicate hydrate (CSH)". The excess calcium silicate hydrate (CSH) intensifies the "interface transition zone (ITZ)" and the pore structure through the optimisation of pore distribution, resulting in a denser microstructure. Additionally, it was discovered that using 30 per cent RHA and 100 per cent recycled coarse aggregate in the concrete preparation allowed it to be shaped at a lower price and, importantly, dropped carbon dioxide emissions while still meeting the technical design requirements. (Behera and Rahman, 2022) The combined effect of RHA and Coarse RCA on the characteristics of RAC remained studied in this investigation. The RAC mixtures were prepared using CRCA as a replacement for coarse natural aggregates at either 0% or 100%. To achieve a deeper comprehension of how RHA impacts the fresh and hardened characteristics of RAC,

different levels of cement replacement with RHA were taken into account, such as 0%, 5%, 10%, 15%, 20%, 25%, and 30%. Mechanical characteristics, such as compression, tension, and flexure, were examined at various ages (7, 28, and 56 days) using experimental tests. Also, other crucial properties like water resistance to penetration and dry density were evaluated. The consequences presented that the different features of RAC improved significantly with an increase in RHA content up to 30%, whereas further increases to 25% led to a decrease in these features. Notably, the compressive strength exhibited a notable increase of approximately 26% at 25% RHA, indicating the high efficacy of RHA utilization. Furthermore, a correlation between the various strength characteristics of RAC mixtures was identified. The increase in porosity resulting from the decreased RHA content contributed to an increase in water permeability and a decrease in dry density of the concrete mixes. This improvement was attributed to the presence of amorphous silica in RHA and its pozzolanic reaction. To overcome the limitations of RAC and ensure the performance of concrete with 100% RCA, the incorporation of low-end pozzolanic ingredients, such as RHA, can be a viable solution.

Table 2.6: Review of Amorphous RHA as an aggregate in concrete

Citation and Author	Aim	Method Used	Limitations
Liu et al., 2022	To investigate the impact of RHA on the mechanical properties and microstructure of recycled aggregate concrete (RAC) when replacing a portion of Portland cement	Various tests on specimens with different contents of RHA and spare ratios for coarse aggregate of recycled concrete, Analysis of microstructure using MIP, SEM, and XRD, Examination of compressive strength, workability, and splitting tensile strength	Limited information on the long-term performance of RAC with added RHA, Potential challenges with workability and splitting tensile strength due to RHA addition

Behera and Rahman, 2022	To study the combined effect of RHA and Coarse RCA on the characteristics of "RAC."	Preparation of "RAC" mixtures with CRCA replacing coarse natural aggregates at 0% or 100%, Various levels of cement replacement with RHA (0% to 30%), Examination of mechanical characteristics (compression, tension, flexure) at different ages, Evaluation of water resistance, dry density, and other properties	Limited information on specific reasons for decreased features at higher RHA content, Challenges in maintaining performance with 100% RCA, suggesting the need for additional pozzolanic ingredients like RHA
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2.1.5 Material for improving the durability and corrosion resistance performance

A potential substance for refining the resilience and corrosion confrontation of many building materials, notably concrete, is amorphous RHA. Amorphous RHA, which is produced from the skilful scorching of rice husks, has special qualities that make it a useful addition for dealing with structural deterioration issues. Amorphous RHA's pozzolanic reactivity is one of its major contributions to increased durability. Amorphous RHA interacts with calcium hydroxide created during cement hydration when added to concrete mixtures. Additional calcium silicate hydrate gel is produced as a result of this reaction, which aids in the concrete matrix's densification. The higher density increases the material's durability by enhancing its resistance to penetration by hostile chemicals like chloride ions and sulphates. The RHA's amorphous structure is also essential in stopping the entry of dangerous materials into the concrete. The pores and capillary gaps in the concrete matrix are filled with tiny particles of amorphous RHA, which lower permeability. Reduced permeability limits the passage of gases, ions, and water, which are the main causes of concrete degradation. In settings exposed to sea conditions or de-icing salts, where corrosion of reinforcing steel is frequently a concern, this property is very advantageous. A crucial component of durability is corrosion resistance, particularly in reinforced concrete structures where steel reinforcement is vulnerable to corrosion. The development of a more protective and impermeable concrete coating over the reinforcing steel is aided by amorphous RHA. This lessens the chance of corrosion-induced damage and lengthens the structure's service life by preventing corrosive chemicals from penetrating the steel surface. Amorphous RHA is cast off in concrete as an incomplete addition to cement, which promotes sustainability and environmental responsibility. The carbon footprint connected with the manufacture of concrete is decreased by lowering the need for conventional cement. This tackles the

environmental effect of the building sector and is in line with international initiatives to encourage eco-friendly construction methods. Amorphous RHA can be used in the creation of high-performance coatings and repair materials in addition to concrete applications. RHA-infused coatings can offer another layer of defence against outside aggressors, improving the general toughness of constructions. Repair materials, including RHA, can be used to increase the resilience and service life of existing buildings. Although amorphous RHA has a lot of potential for enhancing toughness and resistance to corrosion, it is crucial to take into account variables, including correct mix design, curing circumstances, and long-term performance monitoring. The usage of amorphous RHA in building materials is now being improved, and research and development activities are being carried out to produce industry standards for its efficient inclusion. (Alomayri *et al.*, 2021) fabricated the AACs using blast furnace slag (BFS) as the main forerunner. In order to partly supernumerary BFS as the precursor, different amounts of amorphous raw RHA were employed. It was assessed how RRHA content and curing conditions affected how well AACs performed. Both ambient temperature curative and heat curing at 60 °C for 24 hours, shadowed by ambient temperature curing, were used as curing techniques. Based on the answers of the investigation, it is advisable to utilize RRHA as a replacement for BFS at a 10% dosage, as it resulted in enhanced mechanical and durability properties. In addition, it has been noted that the performance of AACs can be enhanced by subjecting them to thermal curing for a duration of 24 hours prior to curing at room temperature. (Hu *et al.*, 2020) examined was performed on the environmental assessment of the utilization of RHA, the assessment of the pozzolanic action of the equipped RHA, the growth of mortar strength with RHA, the experiment on sulphate attack to explore potential durability, and the optimization of RHA using an improved combustion technique. Based on the results, RHA exhibited the highest compressive strength when combined with lime, displaying a strong pozzolanic reaction with an intense release of heat flow and a rapid consumption-ability of Ca (OH)₂. Furthermore, it employed an enhanced combustion approach and demonstrated a high level of pozzolanic activity. The addition of more RHA to mortars led to an increase in their compressive strengths. The sulphate assault findings indicated that the inclusion of 15% RHA in the paste improved sulphate resistance by stabilizing C-S-H and enhancing the pore structure. The utilization of RHA was found to be environmentally friendly based on a sustainability study that considered energy usage and the emissions of embodied carbon dioxide. The feasibility of using highly reactive RHA as a sustainable mineral additive in cement-based products derived from agricultural waste was confirmed.

Table 2.7: Review of Amorphous RHA Material for improving the durability and corrosion resistance performance

Citation and Author	Aim	Method Used	Limitations

Alomayri et al., 2021	To fabricate Autoclaved Aerated Concretes (AACs) using blast furnace slag (BFS) as the main precursor and evaluate the impact of amorphous raw RHA	Utilization of BFS as the main precursor for AACs, Partial substitution of BFS with different amounts of amorphous raw RHA, Assessment of RRHA content and curing conditions on AAC performance, Use of ambient temperature curing and heat curing at 60 °C for 24 hours followed by ambient temperature curing	Limited information on specific mechanical and durability properties assessed, Lack of details on the long-term performance of AACs with added RRHA
Hu et al., 2020	To examine the environmental assessment, pozzolanic action, mortar strength development, sulphate attack resistance, and optimization of RHA	Investigation of environmental impact of RHA utilization, Assessment of pozzolanic action of RHA, Examination of mortar strength development with RHA, Experiment on sulphate attack, Optimization of RHA using an improved combustion technique, Consideration of sustainability aspects such as energy usage and carbon dioxide emissions	Limited details on specific environmental assessment parameters studied, Lack of information on the duration and conditions of the sulphate attack experiment, Generalized information on mortar strength development with RHA

2.2 Crystalline RHA

RHA, which has a crystalline atomic structure, stands out as a special kind that has unique characteristics and possible uses. When rice husks are burned, regulated conditions that promote silica crystallisation are used to create crystalline RHA. Higher temperatures and certain processing methods are frequently needed for this. In contrast to the disorganised, non-crystalline organisation present in amorphous RHA, the resultant crystalline structure. RHA's reactivity and performance in many applications can be strongly impacted by the characteristics of crystalline RHA, which can be very different from its amorphous companion. One important factor is crystalline RHA's reactivity,

which may be different from the strong pozzolanic reactivity connected to amorphous RHA. The impact of the crystalline structure on interactions with cementitious materials and how to best employ it in concrete mixtures is a topic of ongoing research. It is crucial to comprehend the crystalline RHA's reactivity in order to successfully include it in building materials, where pozzolanic reactions are crucial in boosting strength and durability. Construction, refractories, ceramics, and silicon manufacture are just a few of the areas where crystalline RHA finds use. RHA's behaviour might vary according to the particular crystalline structure types it contains, such as cristobalite or tridymite. The many uses show how flexible crystalline RHA can be and how it may contribute to various material qualities based on the needs of the business. There are issues and things to think about while using crystalline RHA. Health and safety are a major concern, particularly the possibility of exposure to airborne crystalline silica particles. To reduce health concerns when handling and processing crystalline RHA, precautions and rules must be put in place. To guarantee the appropriate use of crystalline RHA in diverse applications, researchers and business experts collaborate to create safe practices and recommendations. Exploring the characteristics and possible uses of crystalline RHA requires constant study. Researchers are studying the impact of crystallinity on mechanical, thermal, and chemical characteristics. The objective is to utilise crystalline RHA to its maximum capacity in diverse industrial and construction settings. This study is essential for deepening our comprehension of the substance and maximising its application for enhanced performance across a range of applications. By reusing a waste product from the agriculture industry, the usage of crystalline RHA is in accordance with sustainability objectives in terms of its impact on the environment. The manufacture of crystalline RHA is more energy-efficient than the production of conventional building materials because of the controlled combustion process. Whether RHA is used in crystalline or amorphous form, doing so with consideration for the environment helps reduce waste and the environmental impact of disposal. (Zainal *et al.*, 2019) Examined how much hardness a ceramic filtering membrane comprised of rice husk amorphous and crystalline silica generated, Crystalline silica treated with chemical (CS1), crystalline silica untreated with chemical (CS2), amorphous silica untreated with chemical (AS2) and amorphous silica treated with chemical (AS1) were the four types of material studied. The rice husk was subjected to scanning electron microscopy (SEM)" an "x-ray diffractometer (XRD)" was used to control the silica's characteristics, and a microhardness tester machine was used to measure the hardness. As a result, the silica surfaces of samples AS1 and AS2 were uneven, crinkled, or grainy, whereas the surfaces of samples CS1 and CS2 were flushed, unwrinkled, and flat. Crystalline silica treated chemically (CS1) sample yielded a high hardness value of 171.0. to a 2-hour burning procedure at 700°C and 1000°C in instruction to get the silica stages. The characteristics of the silica were acquired through the utilization of "Scanning Electron Microscopy (SEM)" and "X-ray Diffractometer (XRD)", while the hardness measure was determined by means of a microhardness sample machine. As a result, SEM analysis indicated that both AS1 and AS2 samples, crinkled or grainy surfaces, exhibited an irregular, whereas CS1 and CS2 samples displayed an unwrinkled, flushed, and planar surface. Regarding the high hardness value, the crystalline silica, namely the CS1 example, was found to possess a value of 171.0 when subjected to chemical treatment.

Table 2.8: Review of Crystalline RHA

Citation and Author	Aim	Method Used	Limitations
Zainal et al., 2019	To examine the hardness of a ceramic filtering membrane made from rice husk amorphous and crystalline silica	Preparation of four types of materials: CS1, CS2, AS1, and AS2. Scanning Electron Microscopy (SEM) and X-ray Diffractometer (XRD) for silica characteristics, Microhardness tester machine for hardness measurement	Limited information on the specific application or purpose of the ceramic filtering membrane, Lack of details on the duration or conditions of the burning procedure, Generalized information on the SEM and XRD analyses

2.2.1 As a replacement material for cement

Controlled combustion conditions used in the synthesis of crystalline RHA lead to a highly ordered atomic structure. The reactivity and performance of RHA, when added to cementitious materials, can be affected by its crystalline nature. The subtleties of how crystalline RHA interacts with cement and how its incorporation may impact the mechanical, thermal, and chemical qualities of the finished product are still being studied. The possible reactivity of crystalline RHA as a cement substitute is an important factor to take into account. RHA is recognised for having a strong pozzolanic reactivity when it is amorphous; however, the crystalline form may behave differently. Pozzolanic materials often create calcium silicate hydrate (C-S-H) gel when combined with lime, which increases the material's strength and durability. For crystalline RHA to function optimally as a cement replacement, it is crucial to comprehend its pozzolanic reactivity. By lowering the need for conventional cement, a key contributor to carbon emissions, crystalline RHA, when used as a cement substitute, helps achieve sustainability goals. The process of making cement uses a ration of energy and produces a ration of CO₂. Construction practises may become more ecologically friendly by reusing waste materials and lowering the overall carbon footprint connected with concrete manufacturing by using crystalline RHA, which is obtained from an agriculture sector byproduct.

Beyond environmental concerns, adopting crystalline RHA as a cement substitute may have other benefits. Whether amorphous or crystalline, RHA's smaller particle size results in better packing density inside the concrete matrix. As a result, the material may have increased strength and durability and may be more resistant to many types of degradation, including cracking and chemical assault. (Lo *et al.*, 2021) researched to assess the potential application of RHA, "coal bottom ash (CBA)", and "coal fly ash (CFA)" as part substitutes for regular Portland cement in porous existing.

Using these ash products as single or binary alternatives for cement components, porous concrete samples were tested experimentally to see how well they performed. In analysing the ash resources and porous concrete samples, different methods remained used, such as X-ray powder diffraction, field emission scanning electron microscopy, and Fourier transform infrared spectroscopy, X-ray fluorescence spectroscopy. In addition, the quality of the previous concrete was assessed by analysing its compressive strength, water permeability, and the quantity of metals released during the toxicity characteristic leaching process (TCLP). Results indicated that compared to previous tangible with single-ash incomplete replacements of “CBA and CFA”, the control group and specimens containing RHA exhibited lower compressive strengths. However, at 90 days, the porous concrete examples with second incomplete substitutes of CFA, RHA, CBA, and sintered CBA demonstrated a synergetic result and exhibited advanced compressive strengths compared to the switch collection and specimens with single-ash incomplete replacements of RHA. The concentrations of metals released during TCLP from all specimens met the regulatory criteria in Taiwan, while the water penetrability reached from 0.10 to 0.31 cm/sec. In addition, the carbon footprint analysis revealed that replacing ash components with other materials resulted in a decrease in the overall carbon footprint per m³ of previous concrete by 9.9% to 20.6% when compared to the control collection. In conclusion, the answers to this education show that the presence of CFA, CBA, and RHA as replacements for epoxy resin materials may produce pervious concrete with acceptable compressive strength and water permeability.

Table 2.9: Review of Crystalline RHA as a replacement material for cement

Citation and Author	Aim	Method Used	Limitations
Lo et al., 2021	To assess the potential application of RHA, CBA, and CFA as incomplete substitutes for regular Portland cement in porous concrete	Experimental testing of porous concrete samples with ash products as partial replacements, Analysis of ash resources and porous concrete samples using X-ray powder diffraction, SEM, FTIR, and XRF, Assessment of compressive strength, water permeability, and metal concentrations during TCLP, Carbon footprint analysis	Limited details on specific proportions of RHA, CBA, and CFA used in the mixtures, Lack of information on the specific regulatory criteria used for TCLP, Generalized information on SEM, FTIR, and XRF analyses

2.2.2 As a mineral admixture

As a mineral additive in building materials, crystalline RHA offers an interesting way to improve the effectiveness, viability, and durability of numerous applications. The highly organised atomic structure of crystalline RHA, in contrast to its amorphous version, may have an impact on how it behaves when added to other minerals. Controlled combustion settings are used to produce crystalline RHA by burning rice husks under circumstances that encourage silica to crystallise. Its reactivity and potential advantages, when applied to building materials, can be impacted by the crystalline form that results. An ongoing investigation is being conducted to learn how RHA interacts with cementitious materials and how its crystalline structure may improve the quality of the finished product. RHA may behave differently or respond differently depending on the precise crystalline structures it contains, such as cristobalite or tridymite. The goal of this research is to better understand how different crystalline forms of RHA affect the characteristics of building materials so that its integration as a mineral additive is optimised for the required performance results.

Additionally, by lowering the need for conventional cement in building materials, the use of crystalline RHA as a mineral additive is consistent with sustainability objectives. Construction can reduce carbon emissions by partially substituting cement with RHA, which is made from agricultural waste. Cement manufacturing is recognised for its high carbon emissions. (Nduka *et al.*, 2022) investigated the toughness characteristics of Class 1 of High-performance concrete (HPC) when mixed with RHA as a fractional substitute. A total of six HPC blends were prepared, incorporating various proportions of RHA and likened to a switch blend containing only CEM II. Innovative techniques like laser PSD, Brunauer-Emmett-Teller (BET), “X-ray fluorescence (XRF)”, “Fourier transform infrared/attenuated total reflection (FTIR/ATR)”, “X-ray diffraction (XRD)”, and “scanning electron microscopy (SEM)”, were used for the examination of the binders. These examinations focused on investigating specific surface area (SSA), oxide compositions, particle size distribution (PSD), morphology, mineralogical phases, and functional groups, with the aim of understanding the impact of RHA on HPC. Furthermore, the durability properties of the HPC samples, including sorptivity, chemical attack, and water absorption, were examined to evaluate the inspiration of RHA on the HPC medium. The consequences designated that RHA-based HPCs exhibited durability properties that fell within an acceptable range according to pertinent values. The responses, therefore, imply that using self-produced RHA instead of adhesive in HPC would be advantageous. Scalable manufacturing of RHA might improve sustainable technologies because it is an economically advantageous agricultural waste.

Table 2.10: Review of Crystalline RHA as a mineral admixture

Citation and Author	Aim	Method Used	Limitations

Nduka et al., 2022	To investigate the toughness characteristics of Class 1 High-performance concrete (HPC) when mixed with RHA as a fractional substitute	Preparation of six HPC blends with various proportions of RHA, Analysis using laser PSD, BET, XRF, FTIR/ATR, XRD, and SEM to study specific surface area (SSA), oxide compositions, particle size distribution (PSD), morphology, mineralogical phases, and functional groups, Examination of durability properties (sorptivity, chemical attack, water absorption) to evaluate the influence of RHA on HPC	Lack of specific details on the proportions of RHA used in the blends, Limited information on the specific values considered for the acceptable range of durability properties, Generalized information on SEM, XRD, and other analyses
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2.2.3 As a filler in concrete

In the construction sector, using crystalline RHA as a filler has shown to be a viable and promising option. Due to its pozzolanic qualities, particularly when converted into a crystalline state, RHA, a byproduct of the rice milling process, has attracted interest for inclusion. Due to its special property, it may chemically react with calcium hydroxide, a consequence of cement hydration, to produce more cementitious materials. Concrete's strength and durability are increased by this pozzolanic reaction, making it a desirable choice for improving the performance of building materials. The advantages of incorporating crystalline RHA in encompassing improved workability and concrete are manifold: enhanced durability, reduced heat of hydration, and sustainable waste utilization. The key advantage of crystalline RHA lies in its pozzolanic nature, which allows it to undergo a reaction with calcium hydroxide, forming compounds such as calcium silicate hydrate (C-S-H) gel. This gel plays a vital role in binding the concrete particles together, thereby resulting in augmented strength and durability. The addition of crystalline RHA can exert an optimistic effect on tangible workability. The finely divided particles of RHA can serve as fillers, reducing the water demand and making the concrete mixture more manageable during the construction process. This improved workability proves particularly advantageous in achieving a uniform and well-compacted concrete mix. Another significant benefit is the reduction in the heat of hydration. The excessive generation of heat during the hydration process of cement can give rise to thermal cracking and impact the overall durability of the structure.

The utilization of crystalline RHA has been documented as a means to alleviate this concern through

the reduction of the exothermic reaction during hydration, thus rendering it a highly valuable component in the construction of large-scale concrete structures where the management of thermal dynamics is of utmost importance. The inclusion of crystalline RHA in concrete mixtures also plays a significant role in fostering the eco-sustainability of construction methodologies. By taking advantage of RHA as a byproduct of the rice milling industry, one can provide an environmentally conscious alternative to traditional fillers while simultaneously addressing the predicament of agricultural waste disposal. Through the utilization of waste materials like RHA, the building subdivision can efficiently contribute to the mitigation of the environmental consequences associated with rice milling activities and promote the establishment of a circular economy. (Kwan *et al.*, 2020) used to assess the performance of acid-leached RHA in concrete and the possible advantages of treating rice husk with acid before burning it. Previous research has underscored the rank of eliminating carbon-based and metallic layers, particularly detrimental alkalis like K_2O and Na_2O , from RHA through acid leakage before combustion. Acid leaching can facilitate the production of RHA, which contains a substantial amount of reactive amorphous silica. Acid leaching parameters include the acid concentration, type of acid, leaching temperature and leaching duration. The literature consistently agrees that variations in acid concentration do not have a significant impact.

Table 2.11: Review of Crystalline RHA as a filler in concrete

Citation and Author	Aim	Method Used	Limitations
Kwan et al., 2020	To assess the performance of acid-leached RHA in concrete and explore the potential benefits of treating rice husk with acid before burning it	Evaluation of the impact of acid leaching on RHA, Investigation of parameters such as acid concentration, type of acid, leaching temperature, and leaching duration	Lack of specific details on the concrete performance metrics assessed, Limited information on the specific acids used and their concentrations, Generalized information on the effects of acid leaching parameters

2.2.4 As aggregate in concrete

The use of crystalline RHA as a tangible constituent is an innovative approach in the field of construction. RHA, a byproduct of the rice milling process, can serve as an alternative aggregate material with unique benefits when it undergoes crystallization. This technique has attracted attention because of its capacity to improve concrete properties and promote sustainable construction methods. A primary advantage of employing crystalline RHA as an aggregate lies in its pozzolanic properties. When incorporated into the composition of concrete, RHA undergoes a reaction with

calcium hydroxide, resulting in the formation of extra cementitious resources. Consequently, the inclusion of RHA serves to improve both the asset and toughness of the tangible. In count to providing mechanical strength, the crystalline form of RHA also contributes to the chemical makeup of the concrete, thereby yielding a more robust and long-lasting material. Furthermore, the utilization of crystalline RHA as an aggregate holds the potential to positively influence the workability of concrete. The finely divided particles of RHA possess the ability to fill gaps between larger aggregate particles, thereby improving the overall density of the concrete mixture. This improved packing arrangement grants the mixture a greater degree of pliability and cohesiveness, ultimately facilitating the process of placement and compaction during construction endeavours.

The presence of crystalline RHA as a constituent in concrete has the potential to tackle the environmental issues linked to traditional aggregates. This strategy, which makes use of a byproduct of the rice milling sector, endorses sustainable waste management practices and lessens the adverse environmental effects of concrete manufacturing. The recycling of RHA as an aggregate adheres to the principles of a circular economy, wherein waste materials are repurposed to generate value in innovative applications. (Amin *et al.*, 2021) investigated and conducted with a focus on using advanced machine learning techniques, particularly the artificial neuro-fuzzy inference system and artificial neural network, to estimate the compressive strength of RHAC. By referring to existing scholarly literature, six key factors were identified as input variables, namely the percentage of RHA, the age of the specimen, the properties of the aggregates, the percentage of superplasticizer, the quantity of water, and the amount of cement. This research training presented evidence of the benefits provided by machine learning approaches in terms of reducing both the financial costs and time required for conducting laboratory experiments aimed at determining the optimal composition ratios of RHAC. (Ogwang *et al.*, 2021) The RHA's composition and crystallinity were examined using X-ray fluorescence and diffraction techniques, respectively. The formulation of a geo-polymer filling optical prism was executed in accordance with the standard EN 196-1, utilizing the loose-fitting residue with the highest silica gratified in conjunction with metakaolin, aggregate, water, and an alkaline activator. The dry basis of the ash content in the various rice variabilities ranged from 18.30% to 28.60%. The formless ash achieved at 600 °C was employed for the preparation of geopolymer grouts. Following a 7-day curing process, the mortar's compressive and flexural strength reached 1.5 and 1.3 MPa, respectively. These findings indicate the potential of the gunfire protocol to produce pozzolanic ash for utilization in plaster manufacture.

Table 2.12: Review of Crystalline RHA as an aggregate in concrete

Citation and Author	Aim	Method Used	Limitations

Amin et al., 2021	To estimate the compressive strength of RHAC using advanced machine-learning techniques.	Utilization of artificial neural network and artificial neuro-fuzzy inference system Identification of input variables: RHA percentage, age of the specimen, aggregate properties, superplasticizer percentage, water quantity, and cement amount	Lack of specific details on the dataset used for training the machine learning models - Generalized information on the benefits of machine learning approaches without concrete examples
Ogwang et al., 2021	To examine the composition and crystallinity of RHA and evaluate its potential in geopolymer grouts	X-ray fluorescence and diffraction techniques for ash composition and crystallinity, Formulation of geopolymer grouts according to standard EN 196-1	Limited details on the specific properties assessed for geopolymer grouts, Lack of information on long-term performance or additional characteristics of the geopolymer grouts

2.2.5 Material for improving the durability and corrosion resistance performance

The use of crystalline RHA as a component in construction indicates noteworthy potential for enhancing the endurance and corrosion resistance of structures. RHA, a spinoff of rice crushing manufacturing, possesses distinct characteristics in its crystalline form that can positively impact the performance of concrete in harsh environments. When added to concrete, it responds with calcium hydroxide to create complementary cementitious materials like calcium silicate hydrate gel. This reaction intensifies the overall asset and toughness of the concrete, making it more resistant to various environmental factors. The endurance of concrete performance is especially important in demanding conditions. Crystalline RHA, acting as an additional cementitious material, reduces the permeability of concrete. The formation of additional C-S-H gel helps fill the pores and capillaries in the concrete matrix, thereby reducing the pathways for the ingress of harmful substances such as water, chloride ions, and sulphates. This increased resistance to permeability can significantly improve the endurance of concrete structures by mitigating issues such as freeze-thaw damage and chemical attacks. Corrosion resistance constitutes another domain wherein crystalline RHA can fulfil a beneficial role. In reinforced concrete structures, chloride ions originating from de-icing salts or

marine environments can induce the corrosion of steel reinforcement, thereby jeopardizing the structural integrity of the concrete. The utilization of crystalline RHA fosters the creation of a denser and more impervious concrete matrix, acting as a barrier against the infiltration of chloride ions and other corrosive substances. This, in turn, augments the corrosion resistance of the steel reinforcement, leading to an extended service life for the structure. Furthermore, crystalline RHA has been documented to diminish the potential of alkali-silica reaction (ASR) in concrete. ASR signifies a chemical reaction between specific reactive minerals in aggregates and the alkaline solution in concrete, which triggers the generation of a gel that can induce expansion and cracking over time. By mitigating the occurrence of ASR, crystalline RHA contributes to the long-term endurance of concrete structures. In order to effectively implement crystalline RHA to enhance durability and corrosion resistance, careful consideration must be given to factors such as quality control, appropriate dosage in concrete mixtures, and adherence to pertinent testing standards. It is of utmost importance to conduct comprehensive testing to evaluate the impact of crystalline RHA on concrete properties, encompassing compressive strength, permeability, and resistance to aggressive environmental conditions.

(Wang *et al.*, 2021) The investigation was conducted on the physicochemical characteristics of RHA and their influence, including their strength, on cement-based materials, chloride penetration, cement hydration, sulphate resistance, carbonation, and shrinkage. These answers were obtainable and designated. Furthermore, a complete discourse was assumed to discuss the hydration device and the generally best content variety of RHA. The closure reaction of microparticles and the dispersion response of macroparticles are the two primary modes of hydration for RHA atoms. While the interior curing impact of RHA is mostly associated with large-sized atoms, the biochemical influence of RHA is primarily attributed to the action of small-sized atoms on the cementitious scheme. It may be deduced that the preferred satisfied range of RHA lies between 10% and 20% by condensing and deleting the macro-properties. The use of RHA in ecologically friendly and sustainable cement-based materials may be made easier with the help of a more in-depth understanding and coherence of the action mechanism of RHA in cementitious materials. (Venyite *et al.*, 2021) Proposed that the alkaline activation of laterites was carried out by utilizing prepared RHA-based sodium silicate. The final characteristics of the geopolymer products were influenced by the varying sizes of metakaolin (MK) and basalt powder (BA). The evolution phases were examined after a 28-day curing period at room temperature using SEM, XRD, and FT-IR. The highest compressive strength of the uncalcined laterite-based formulations was observed. Beyond these thresholds, the strength diminished, and the setup time increased. Calcined laterite was used instead of basalt powder to diminish strength and control sample porosity at low levels. In comparison to metakaolin added to raw laterite-based formulations, basalt powder added to calcined laterite-based formulations significantly reduced water absorption and perceived porosity. However, the bulk density mostly remained unaltered. The RHA-based alkaline activator, produced locally, was successful in causing laterite to polymerize and produced materials with robust mechanical and physical properties suitable for high-quality housing applications. (Thiedeitz *et al.*, 2022) Conducted an examination of the urgent global demand for more environmentally friendly building materials, specifically the use of RHA as an additional SCM. The

examination encompassed the evaluation of the pozzolanic activity and microstructural characteristics by way of X-ray Diffraction (XRD) analysis and Scanning Electron Microscopy (SEM). Also, the durability properties and compressive strength of the mortars were appraised. These properties were then compared to those of mortars that did not contain SCM or contained equal quantities of fly residue and mineral dust. The toughness soundings, which included carbonation confrontation and tube force, demonstrated that RHA mortars performed better due to their compact microstructure. The assessment of the microstructure disclosed that during the initial stages of hydration, particularly within the first few hours after the introduction of water, the RHA mortars exhibited an accelerated response rate, resulting in heightened heat flux and the formation of hydration products. The XRD analysis indicated a significant pozzolanic reaction, as demonstrated by a reduction in crystalline phases with longer hydration times. Overall, these soundings deliver valuable visions of the suitability of RHA in concrete. Low water absorption, improved growth of strength, and minimal capillary absorbency all designate RHA as an appropriate pozzolanic preservative for maintaining and hard-wearing tangible.

(Dawoud *et al.*, 2023) Investigated and examined the utilization of RHA as an income to recover the features of Portland cement, which is employed in the solidification of radioactive waste. Both untreated and Potassium Hydroxide (KOH)-treated RHA, loaded with Cobalt, Strontium, and Cesium, were affixed to ordinary Portland cement. Instead of Cobalt, Strontium, and Cesium isotopes, Cobalt, Strontium, and Cesium ions were employed in this study due to their similar chemical behaviour to radioisotopes. The investigation encompassed an examination of the mechanical properties, the impact of temperature on the compressive strength, and the behaviour of leaching for the ultimate solid waste block. The results revealed that compressive strength experiences an upsurge in correspondence with the growing number of additives incorporated into the untreated RHA, while conversely, it diminishes for blocks composed of KOH-treated RHA. Thermogravimetric analysis (TGA) and Infrared analysis (IR) were undertaken. The leaching process was scrutinized with respect to the result of the interaction period and early attentiveness, utilizing distilled water and underground water as the leachants. The findings attest to the successful utilization of OPC in the solidification and stabilization of radioactive waste, and the utilization of RHA as a substitutive cementitious material has proven to be efficacious in augmenting the attributes of the cemented radioactive waste matrices.

Table 2.13: Review of Crystalline RHA Material for improving the durability and corrosion resistance performance

Citation and Author	Aim	Method Used	Limitations

Wang et al., 2021	To investigate the physicochemical characteristics of RHA and its influence on cement-based materials, including strength, chloride penetration, cement hydration, sulphate resistance, carbonation, and shrinkage	Analysis of various properties such as strength, chloride penetration, cement hydration, shrinkage, sulphate resistance, and carbonation.	Lack of specific details on the experimental setups for individual tests, Generalized information on the optimal content range without specifying the context of individual applications
Venyite et al., 2021	To propose the alkaline activation of laterites using prepared RHA-based sodium silicate and evaluate the characteristics of geopolymer products	Utilization of RHA-based sodium silicate for alkaline activation – Influence of varying sizes of metakaolin (MK) and basalt powder (BA) on geopolymer products, Examination of evolution phases using SEM, XRD, and FT-IR	Limited information on specific geopolymer product properties assessed, Lack of detailed information on the long-term performance of geopolymer products
Thiedeitz et al., 2022	To evaluate the pozzolanic activity, microstructural characteristics, durability properties, and compressive strength of mortars with RHA as an additional SCM	Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) analysis for pozzolanic activity and microstructural characteristics, Appraisal of durability properties and compressive strength of mortars	Lack of specific details on the experimental conditions and parameters for each assessment, Generalized information on the enhanced performance of RHA mortars without specific quantification

Dawoud et al., 2023	To examine the utilization of RHA as an additive to recover the features of Portland cement in the solidification of radioactive waste	Use of untreated and Potassium Hydroxide (KOH)-treated RHA loaded with Cobalt, Strontium, and Cesium, Examination of mechanical properties, the impact of temperature on compressive strength, and leaching behaviour	Lack of specific details on the concentration levels of Cobalt, Strontium, and Cesium ions, Limited information on the specific characteristics of the solidified radioactive waste matrices, and Generalized information on the successful utilization of RHA without specifying concrete results
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