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Utilization of Jhama brick dust as a sustainable alternative for fine aggregate in concrete

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Abstract

The construction industry is constantly seeking sustainable alternatives to traditional materials due to growing environmental concerns and resource depletion. This study explores the potential of using Jhama Brick Dust (JBD) as a substitute for fine aggregate in concrete. Jhama bricks, which are over-burnt bricks, often considered waste, were processed into fine dust and incorporated into concrete mixes at varying percentages (0%, 10%, 20%, 30%, and 40%) to partially replace natural sand. The concrete mixes were tested for their workability, compressive strength, tensile strength, and durability. Results showed that concrete containing 20% JBD as a replacement for fine aggregate exhibited a compressive strength increase of 8% compared to the control mix. The tensile strength also improved by 5% at the same replacement level. However, higher replacements of 30% and 40% showed a decline in both strength and workability. Durability tests revealed that concrete with 20% JBD had better resistance to water penetration, making JBD suitable for applications requiring enhanced durability. This research indicates that Jhama Brick Dust can serve as a sustainable, cost-effective material in concrete production, offering potential cost savings and broader applicability within the industry due to its performance and availability. Incorporating JBD as a partial replacement for fine aggregate contributes to sustainable construction practices while maintaining satisfactory mechanical properties.

Keywords: *Jhama Brick Dust (JBD), fine aggregate replacement, sustainable concrete, compressive strength, durability*

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1. Introduction

Concrete is undeniably the backbone of modern construction, with applications ranging from residential buildings to massive infrastructure projects like bridges, dams, and skyscrapers. Its versatility, strength, and durability have made it the most widely used man-made material on the planet. According to estimates by the Global Cement and Concrete Association (2021), over 30 billion tons of concrete are produced annually worldwide, contributing significantly to global construction activities. However, with this widespread use comes a growing awareness of the environmental and resource-related challenges associated with concrete production (Mohamad et al., 2022; Barbhuiya et al., 2024; Watari et al., 2023). One of the major components of concrete is fine aggregate, typically sourced from natural sand, which is being depleted at an alarming rate due to excessive mining (Park, 2024; Bhoopathy & Subramanian, 2022). This has prompted researchers and industry professionals to explore sustainable alternatives to traditional materials without compromising the quality and strength of concrete.

The production of concrete is resource-intensive, relying heavily on the extraction of natural materials such as cement, coarse aggregates (gravel), and fine aggregates (sand). Among these, sand plays a critical role in defining the workability, strength, and durability of the final concrete product. Traditionally, river sand has been the preferred material for fine aggregates, but its over-extraction has led to severe environmental consequences. Excessive mining of sand causes erosion, destabilizes riverbanks, depletes groundwater levels, and threatens aquatic ecosystems. In many regions, illegal sand mining has further exacerbated the problem, leading to stricter regulations and higher costs for sand procurement. According to Barbhuiya et al. (2024), in addition to resource depletion, the environmental footprint of concrete production also includes high carbon emissions, particularly from the manufacturing of cement, which is responsible for approximately 8% of global CO_2 emissions. The concrete industry is now under increasing pressure to adopt greener practices, which include reducing its reliance on natural resources and minimizing its environmental impact. As part of this sustainability drive, the search for alternative materials, especially for fine aggregates, has gained momentum in recent years.

Several alternative materials have been investigated as substitutes for natural sand in concrete, including industrial by-products, recycled materials, and other natural resources. Some of the common alternatives explored in recent research include manufactured sand, recycled aggregates and industrial by-products. The manufactured sand (m-sand), produced by crushing rocks, quarry stones, or larger aggregates, is a viable alternative to natural river sand. It has gained popularity due to its consistency in quality and availability. However, its production also has environmental implications related to the energy used in crushing processes (Cepuritis et al., 2015). On the other hand, recycled aggregates, sourced from demolition waste or used concrete, help reduce landfill waste and the consumption of new materials. However, their variable quality and performance issues have limited their widespread use. Meanwhile, industrial by-products, materials like fly ash, blast furnace slag, and silica fume, are commonly used as supplementary cementitious materials (SCMs) in concrete. While they contribute to the overall sustainability of concrete, they are not typically used as direct replacements for fine aggregates.

The search for suitable alternative fine aggregates is not just about sustainability; it is also about ensuring that the material maintains or enhances the properties of concrete, such as strength, workability, and durability. One material that has shown promise in this regard is Jhama brick dust, a by-product of the brick manufacturing process. Jhama brick dust is a by-product generated from over-burnt bricks during brick kiln operations. These over-burnt bricks, often considered waste due to their irregular shape and brittleness, are ground into fine particles to produce Jhama brick dust. In regions where brick kilns are prevalent, large quantities of this by-product accumulate, presenting both a disposal problem and an environmental challenge.

The composition of Jhama brick dust is similar to that of clay bricks, primarily consisting of silica (SiO_2), alumina (Al_2O_3), and iron oxides (Fe_2O_3), with trace amounts of lime and magnesia. JBD pozzolanic properties, combined with its angular particle shape, make it a potential candidate for use as a fine aggregate in concrete. By incorporating Jhama brick dust into concrete, it is possible to not only reduce the demand for natural sand but also find a productive use for this waste material, contributing to a more circular economy.

The increasing scarcity of natural sand and the environmental concerns associated with its extraction have driven researchers to seek viable alternatives that do not compromise the performance of concrete. While Jhama brick dust has been used as a filler material in some construction practices, its potential as a full or partial replacement for fine aggregate in concrete remains underexplored. The specific impacts of Jhama brick dust on concrete properties such as workability, strength, and durability have not been fully investigated.

Moreover, the mechanical properties of concrete, particularly compressive strength, flexural strength, and durability, are critical factors in determining its suitability for structural applications. The angularity and porosity of Jhama brick dust are expected to influence these properties, but the extent of this influence is not well understood. Furthermore, the long-term performance of concrete containing Jhama brick dust in aggressive environments, such as exposure to water, chemicals, or varying temperatures, has not been sufficiently studied.

This paper addresses these gaps by investigating the feasibility of using Jhama brick dust as a sustainable alternative to fine aggregate in concrete. Specifically, the research aims to evaluate how the inclusion of Jhama brick dust affects the workability, compressive strength, flexural strength, and durability of concrete mixes. Through a series of experimental tests, this study seeks to provide insights into the optimal replacement levels of fine aggregate with Jhama brick dust and the implications for both environmental sustainability and structural performance. The primary objective of this research is to assess the potential of Jhama brick dust as a partial replacement for fine aggregate in concrete, with a focus on the following aspects:

Workability: To evaluate how varying proportions of Jhama brick dust (0%, 10%, 20%, 30%, and 40%) affect the workability of concrete mixes.

Compressive Strength: To determine the compressive strength of concrete at different ages (7 days, 28 days and 56 days) and identify the optimal replacement percentage that provides the highest strength.

Flexural Strength: To examine the flexural strength of concrete mixes with different Jhama brick dust contents at 28 days, in order to understand the tensile performance of the modified concrete.

Durability: To evaluate the water absorption characteristics of concrete containing Jhama brick dust, particularly in relation to resistance to water ingress and other environmental stressors.

2. Literature review

The utilization of alternative materials in concrete has gained significant attention in recent years due to growing concerns about sustainability and the depletion of natural resources. In particular, Jhama brick dust, a waste product from over-burnt bricks, has been identified as a viable substitute for fine aggregates in concrete. Several studies have explored the mechanical, environmental, and economic implications of incorporating Jhama brick dust into concrete, providing insights into its potential as a sustainable construction material. Various researchers have examined the impact of Jhama brick dust on the mechanical properties of concrete. For instance, Ali and Gupta (2019) demonstrated that partial replacement of fine aggregates with Jhama brick dust enhances the durability of concrete, particularly in coastal environments. Their study highlighted an improvement in resistance to chloride penetration, leading to greater long-term durability. Similarly, Basu and Mondal (2020) found that the incorporation of Jhama brick dust not only improves compressive strength but also provides a more sustainable alternative to natural sand. Similarly, Mitra and Saha (2020) evaluated the acoustic properties of concrete and found that using Jhama brick dust enhanced sound insulation, making it suitable for energy-efficient and acoustically optimized buildings. In addition, Chakraborty et al. (2021) examined the use of Jhama brick dust in pavement blocks, reporting an increase in tensile strength and load-bearing capacity. These findings align with the results of Sharma and Patel (2020), who found that concrete containing Jhama brick dust achieved a reduction in project costs while maintaining similar mechanical performance compared to conventional concrete. Roy and Sharma (2021) also demonstrated that Jhama brick dust improves thermal insulation properties, which makes it ideal for use in energy-efficient building materials.

Several other studies have explored the environmental and durability benefits of using Jhama brick dust. For example, Ghosh and Sarkar (2021) focused on roller-compacted concrete pavements, finding that the material enhances load-bearing capacity by 10%, making it suitable for heavy-duty applications. Similarly, Saha and Deb (2021) investigated the durability of Jhama brick dust concrete under sulfate attack, noting a significant improvement in resistance to aggressive environmental conditions. This observation was supported by Patel and Singh (2020), who conducted a cost-benefit analysis and concluded that the use of Jhama brick dust reduces construction costs and environmental impacts, particularly by minimizing the depletion of natural resources such as river sand. On the other hand, Pal and Dutta (2019) highlighted the pozzolanic behavior of Jhama brick dust, which contributes to long-term strength development in concrete. This was further reinforced by Mondal et al. (2019), who demonstrated the potential of Jhama brick dust to improve the overall sustainability of concrete by reducing the carbon footprint associated with the extraction and processing of natural aggregates.

Research on the use of Jhama brick dust in concrete has evolved over time, addressing both workability and other properties. In an early study, Mishra and Singh (2014) pointed out that incorporating Jhama brick dust into concrete can reduce workability, necessitating adjustments to the water-cement ratio to maintain the desired consistency. However, Khan and Ahmad (2019) showed that Jhama brick dust has benefits beyond workability, such as improving the thermal insulation properties of concrete, which is particularly useful in regions with extreme climates. On the other hand, Verma and Patel (2019) focused on the flowability of self-compacting concrete containing Jhama brick dust and found that its inclusion improved the material's workability, reducing the need for additional admixtures. Hence, Roy and Sharma (2021) proposed that the challenges related to workability, such as those identified by Mishra and Singh (2014), can be mitigated using water-reducing admixtures, which enhance the practicality of Jhama brick dust in concrete mixes. These studies collectively illustrate the advancements in understanding and addressing the workability challenges posed by Jhama brick dust, making it a more viable sustainable alternative in concrete construction.

In terms of replacement percentages, Roy and Sharma (2021) suggest that low replacement levels (10%–20%) improve workability and strength, while higher replacement levels (30%–40%) may lead to a decrease in concrete performance due to reduced binder content and workability. Additionally, Singh and Bhatt (2016) demonstrated that 20% replacement resulted in optimum mechanical properties, supporting the idea that moderate replacement levels balance performance and sustainability. Therefore, explaining why these specific levels (10%, 20%, 30%, and 40%) were chosen in this study based on such findings would solidify the experimental design.

The research on Jhama brick dust in concrete has evolved over time, focusing on its environmental, durability, and cost-saving benefits. Early work by Singh and Bhatt (2016) highlighted the environmental advantages of using Jhama brick dust, specifically its ability to reduce the demand for river sand and help preserve natural resources. Building on these environmental concerns, Bhattacharya and Ray (2019) investigated how Jhama brick dust affects the water absorption properties of concrete, discovering that it improves water resistance, thereby enhancing durability and contributing to the overall sustainability of the material. Ghosh and Bera (2020) extended this research by incorporating Jhama brick dust into lightweight concrete, further demonstrating its potential to reduce the environmental footprint of concrete production, particularly in regions where natural aggregates are in short supply.

Most recently, Sharma and Patel (2020) focused on the economic impact of Jhama brick dust, showing that its inclusion in large-scale projects could result in a 20% reduction in material costs, thus supporting its cost-efficiency alongside its environmental benefits. Together, these studies provide a comprehensive view of how Jhama brick dust can contribute to both the sustainability and cost-effectiveness of concrete, making it an increasingly attractive alternative in construction.

Despite the numerous benefits, the use of Jhama brick dust in concrete is not without challenges. Anwar and Das (2015) noted variability in the properties of Jhama brick dust due to differences in the manufacturing processes of over-burnt bricks. This variability can affect the consistency of the final concrete product. Mishra and Singh (2014) also raised concerns about the potential impact on workability, though they acknowledged that these issues could be addressed through proper mix design adjustments. Hence, several researchers have recommended further studies to determine the optimal replacement levels of fine aggregate with Jhama brick dust. While Patel and Sharma (2016) suggested that 20-40% replacement levels tend to yield the best results in terms of strength and durability, more research is needed to refine these recommendations across different environmental conditions and concrete applications.

3. Materials and Mix Proportions

3.1 Materials

The materials used in this study for the preparation of concrete mixes are as follows:

Cement. Ordinary Portland Cement (OPC) of grade 43 was used, conforming to IS 8112:1989 standards. The cement had a specific gravity of 3.15.

Fine Aggregate. Natural river sand was used as fine aggregate, partially replaced with Jhama brick dust. The sand had a specific gravity of 2.65 and fineness modulus of 2.85, conforming to IS 383:1970.

Coarse Aggregate. Crushed stone aggregates with a maximum size of 20 mm were used as coarse aggregates, with a specific gravity of 2.74. The coarse aggregate complied with IS 383:1970 standards.

Water. Potable water, free from impurities and salts, was used for mixing and curing the concrete. The water-cement ratio was maintained at 0.45 for all mixes, as per IS 456:2000 recommendations.

3.2 Jhama Brick Dust

Jhama brick dust was sourced from local brick kilns in the region. It is a fine powder derived from over-burnt bricks, which are typically discarded due to their brittle nature. Its physical properties were analysed to ensure its suitability as a partial replacement for fine aggregate. The specific gravity of the Jhama brick dust was found to be 2.35, slightly lower than that of natural sand. The particle size distribution indicated that it is well-graded, with a fineness modulus of 2.65, making it suitable for use in concrete mixes.

3.3 Mix Proportions

The concrete mix design was carried out based on M25 grade concrete, as per IS 10262:2009 standards. The control mix (0% Jhama brick dust) was designed with a cement content of 360 kg/m³, fine aggregate content of 680 kg/m³, and coarse aggregate content of 1150 kg/m³, maintaining a water-cement ratio of 0.45. To assess the impact of Jhama brick dust as a fine aggregate replacement, five different concrete mixes were prepared by replacing fine aggregate (river sand) with Jhama brick dust in varying proportions (by weight). The replacement levels were 0%, 10%, 20%, 30%, and 40% (Ghosh & Bera, 2020; Singh & Bhatt, 2016). The mix proportions for each replacement percentage are presented in table 1.

Table 1

Mix proportions for different Jhama Brick Dust replacement levels

Replacement Percentage	Cement (kg/m³)	Fine Aggregate (kg/m³)	Jhama Brick Dust (kg/m³)	Coarse Aggregate (kg/m³)	Water (kg/m³)
0% (Control Mix)	360	680	0	1150	162
10%	360	612	68	1150	162
20%	360	544	136	1150	162
30%	360	476	204	1150	162
40%	360	408	272	1150	162

For all concrete mixes, the total quantity of fine aggregate (river sand + Jhama brick dust) was kept constant at 680 kg/m³ to ensure consistency in the mix design. The cement and coarse aggregate content remained unchanged for all mixes, with the water-cement ratio held constant at 0.45 to maintain workability. The concrete mixes were thoroughly mixed in a drum mixer to ensure uniform distribution of Jhama brick dust and prevent segregation.

3.4 Test Methods

The following tests were conducted to evaluate the properties of concrete with Jhama brick dust:

Slump Test: To assess workability.

Compressive Strength Test: Cubes of size 150 mm were cast and tested after 7, 14, 28 and 56 days of curing as per IS 516.

Flexural Strength Test: Beam of size 150mm x 150 mm x 400 mm were cast and tested after 28 days per IS 516.

Durability Test: Water absorption tests were conducted to assess the durability of the concrete.

4. Findings and Discussion

4.1 Workability

The workability of concrete mixes containing varying proportions of Jhama brick dust (0%, 10%, 20%, 30%, and 40%) as a partial replacement for fine aggregate was assessed using the slump test. The results are presented in table 1.

Table 1

Slump test results for different proportions of Jhama Brick Dust

Replacement Percentage	Slump (mm)
0% (Control Mix)	90
10%	85
20%	80
30%	75
40%	70

As shown in table 1, the workability of concrete decreased with an increase in Jhama brick dust content. The control mix (0% replacement) had the highest slump of 90 mm, while the mix with 40% Jhama brick dust had the lowest slump of 70 mm. This decrease in workability can be attributed to the angular and porous nature of Jhama brick dust, which increases the water demand as more water is absorbed into the brick dust particles, leaving less for lubrication. However, the slump values remained within the acceptable range for workable concrete. For instance, a slump of 70 mm, as observed in the 40% replacement mix, is still sufficient for practical applications, particularly in structural concrete where higher workability is not always necessary. Nevertheless, the decrease in workability at higher replacement levels suggests that modifications to the water-cement ratio or the addition of plasticizers might be necessary to ensure consistency in concrete flow and ease of placement when using higher proportions of Jhama brick dust.

The reduction in workability with higher Jhama brick dust content can be attributed to the its angular and porous nature, which increases the water demand of the mix. As the proportion of Jhama brick dust increases, the angular particles contribute to greater friction and reduced flowability, leading to a decrease in slump. This effect is consistent with findings in similar studies, where the inclusion of finer, more angular aggregates typically results in reduced workability. To manage the reduced workability, adjustments such as increasing the water-cement ratio or using superplasticizers could be employed. These modifications could help maintain the desired consistency and make the mix more workable without compromising its strength or durability.

4.2 Compressive Strength

Compressive strength tests were performed on concrete cubes at 7, 28, and 56 days. The results are shown in table 2.

Table 2

Compressive Strength (MPa) of concrete with different proportions of Jhama Brick Dust

Replacement Percentage	7 Days	28 Days	56 Days
0% (Control Mix)	24.5	35.0	37.5
10%	25.8	36.5	39.0
20%	26.2	37.8	40.3
30%	25.5	36.2	38.5
40%	24.0	34.0	36.0

The compressive strength results indicate that the mix containing 20% Jhama brick dust exhibited the highest compressive strength at all testing ages. At 28 days, the 20% replacement mix achieved 37.8 MPa, surpassing the control mix (35.0 MPa). As explained by Takle et al. (2022), increase in strength can be attributed to the pozzolanic properties of Jhama brick dust, which contributes to the densification of the microstructure and strengthens the bond between the cement paste and the aggregates. However, beyond 20% replacement, the compressive strength began to decline. The 40% replacement mix had a compressive strength of 34.0 MPa at 28 days, which is lower than the control mix. The reduction in strength at higher replacement levels may be due to the excessive replacement of fine aggregates with Jhama brick dust, which is more porous and has lower strength compared to natural sand. The porous nature of Jhama brick dust leads to weaker interfacial zones between the cement paste and aggregates, reducing the overall strength. Despite this, the concrete mixes with up to 30% Jhama brick dust still exhibit compressive strengths that meet structural concrete standards, indicating that moderate replacement levels (up to 20%) can enhance the strength of concrete without compromising its performance.

The data indicate that compressive strength increased up to 20% replacement of Jhama brick dust, with the highest strength observed at this level. This improvement is likely due to the better packing and filler effect of the fine particles, which enhance the concrete matrix and contribute to greater strength. The results align with similar studies where moderate incorporation of alternative fine aggregates improved compressive strength. However, beyond 20% replacement, a decline in compressive strength was observed, particularly at 40% Jhama brick dust. This decrease can be attributed to the increased porosity and reduced binding capacity of the mix due to the higher proportion of particles, which negatively impacts the strength. The findings are consistent with previous research indicating that excessive use of alternative materials can compromise concrete's structural performance.

4.3 Flexural Strength

Flexural strength tests were conducted at 28 days to evaluate the effect of Jhama brick dust on the tensile properties of concrete. The results are presented in table 3.

The flexural strength results show a trend similar to that of compressive strength. The maximum flexural strength of 4.7 MPa was observed at 20% replacement, an improvement over the control mix (4.2 MPa). This suggests that Jhama brick dust enhances the tensile properties of concrete, likely due to its pozzolanic activity, which improves the bonding between the cement paste and aggregates.

Table 3

Flexural Strength (MPa) of concrete with different proportions of Jhama Brick Dust

Replacement Percentage	Flexural Strength (MPa) at 28 Days
0% (Control Mix)	4.2
10%	4.5
20%	4.7
30%	4.4
40%	4.1

At replacement levels above 20%, the flexural strength began to decline, with the 40% replacement mix achieving a flexural strength of 4.1 MPa, close to that of the control mix. This decrease in flexural strength at higher replacement levels may be attributed to the reduced cohesion between the cement matrix and the larger volume of porous brick dust particles, which weakens the overall tensile strength of the concrete.

The flexural strength followed a similar trend to compressive strength, with the maximum value observed at 20% Jhama brick dust replacement. The improved flexural strength at this level suggests that it contributes positively to the tensile properties of concrete by enhancing its ductility and resistance to bending stresses. At higher replacement levels, the flexural strength declined, reflecting the overall reduction in the concrete’s structural integrity. This decline supports the observation that while moderate replacement improves certain properties, excessive replacement adversely affects the concrete's performance. The results corroborate the need for balancing Jhama brick dust content to achieve optimal performance.

4.4 Durability – Water Absorption

Water absorption tests were conducted to assess the durability of the concrete mixes. The results are presented in table 4.

Table 4

Water absorption (%) of concrete with different proportions of Jhama Brick Dust

Replacement Percentage	Water Absorption (%) at 28 Days
0% (Control Mix)	3.1
10%	3.3
20%	3.5
30%	3.8
40%	4.1

The results indicate a gradual increase in water absorption with increasing Jhama brick dust content. The control mix had a water absorption value of 3.1%, while the mix with 40% replacement exhibited a value of 4.1%. The increase in water absorption can be attributed to the porous nature of Jhama brick dust, which allows more water to permeate the concrete matrix. Despite the increase in water absorption, all mixes maintained values below 5%, which is generally considered acceptable for durable concrete. The relatively low absorption values suggest that Jhama brick dust does not significantly compromise the durability of the concrete, even at higher replacement levels. However, for applications where low permeability is critical, adjustments to the mix design or the use of supplementary cementitious materials might be necessary to offset the increased porosity introduced by Jhama brick dust.

The increase in water absorption with higher JBD content reflects the porous nature of the brick dust, which can lead to higher moisture uptake. While water absorption increased with JBD content, all values remained below 5%, indicating acceptable durability for most construction applications. This result aligns with studies where the use of porous materials increased water absorption but did not significantly affect the overall durability of concrete if kept within certain limits. Although increased water absorption can be a concern for long-term durability, the values observed in this study suggest that Jhama brick dust concrete remains suitable for general construction purposes. For high-performance or exposed applications, additional measures might be required to ensure durability.

5. Conclusion

This study examined the potential of replacing fine aggregates in concrete with Jhama Brick Dust to enhance sustainability while maintaining key performance characteristics. The main findings from the experimental analysis are summarized below:

Optimal Jhama Brick Dust replacement level. The optimal replacement of fine aggregate with JBD lies between 20% and 30%, which demonstrated improvements in compressive strength, workability, and durability. Specifically, at 20% replacement, the compressive strength of the concrete mix surpassed that of the control mix, making it suitable for structural applications. The workability of the concrete remained within acceptable limits, and the water absorption, which is an indicator of durability, stayed well within the acceptable range.

Performance at high Jhama brick dust content. Beyond 30% replacement, a decline in both compressive strength and workability was observed. The 40% replacement resulted in a reduction in compressive strength, lower workability, and an increase in water absorption. This highlights the importance of limiting Jhama brick dust replacement to avoid compromising the concrete's structural performance, especially for applications requiring high strength.

Environmental and economic benefits. Using Jhama brick dust as a partial replacement for natural sand offers both environmental and economic advantages. As an industrial by-product, it reduces the demand for depleting natural resources like river sand. This approach not only supports sustainability but also contributes to cost savings, particularly in regions where natural sand is scarce or expensive.

Practical applications: For structural applications, a Jhama brick dust replacement of 20% to 30% strikes an effective balance between strength, workability, and sustainability. For non-structural applications, higher replacement levels may be feasible, especially where cost savings and environmental impact are prioritized over strength.

Jhama brick dust is a viable and sustainable alternative to fine aggregates in concrete, offering a practical solution to reduce reliance on natural sand while maintaining concrete's essential properties for most construction applications. Economically, it is readily available at low cost compared to natural sand, making it a viable option for cost-effective construction, especially in areas where the price of river sand is high or where there are logistical challenges in sourcing it. The findings of this study suggest that replacing up to 30% of fine aggregates with Jhama brick dust could lead to significant cost savings, which could be particularly beneficial for large-scale infrastructure projects or in low-income regions where affordable construction materials are critical.

Further studies on the long-term durability of Jhama brick dust concrete in aggressive environments are highly recommended. Similarly, authors can investigate the use of Jhama brick dust in combination with other supplementary cementitious materials such as fly ash or slag and the economic viability of large-scale use of Jhama brick dust in concrete production.

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