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MatSci Express
ISSN: 2997-8440 www.aristonpubs.com/matsci-express https://doi.org/10.69626/mse.2024.0269

RESEARCH ARTICLE

Experimental Analysis of Thermal and Mechanical Properties of Mortar Incorporating Agricultural Waste Materials

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ABSTRACT: This study explores the thermal conductivity and mechanical properties of mortar compositions incorporating agricultural waste materials, specifically Rice Husk Ash (RHA) and Bagasse Ash (BA), as sustainable alternatives. Experimental results indicate a marked reduction in thermal conductivity as agro-waste content increases. Notably, Rice Husk Ash-based mortar (RH15) and Bagasse Ash-based mortar (BA15) exhibit reductions in thermal conductivity of 19°C and 17°C, respectively, when compared to traditional Portland Pozzolana Cement (PPC) mortar after four hours of exposure. In geopolymer mortars, mix 7 demonstrates superior thermal performance, with RHA and BA reducing thermal conductivity by 12°C and 14°C, respectively, compared to Fly Ash-based Geopolymer mortar (FA7). The study also evaluates the shrinkage tendencies of the mortars, revealing that higher agro-waste content mitigates shrinkage, with Bagasse Ash-based mortars showing the lowest linear shrinkage at 5% sand replacement. Mechanical strength analysis further highlights the beneficial effects of Bagasse Ash, particularly in PPC-based mortars, where strength improvements are observed at both 5% and 15% sand replacement. Among geopolymer mixes, mix 7 emerges as the optimal design in terms of both thermal and mechanical performance. These findings emphasize the potential of agricultural waste materials to enhance the sustainability and efficiency of mortar compositions, contributing to reduced environmental impact and improved construction materials.

Keywords: Rice Husk Ash (RHA), Bagasse Ash (BA), Fly Ash (FA), thermal conductivity, Geopolymer mortar, sustainable materials.

Received: 13 June 2024; Revised: 07 July 2024; Accepted: 25 July 2024; Published Online: 01 August 2024

1. INTRODUCTION

The built environment significantly influences the natural ecosystem, contributing to the consumption of resources and the generation of carbon emissions [1]. As the global population continues to grow, the demand for construction materials and infrastructure will inevitably rise, further increasing environmental impacts. In light of this, achieving sustainability in construction has become a pressing concern. There is a growing recognition of the need to adopt greener construction methods that prioritize environmental responsibility while maintaining functionality and performance [2]. One area of focus is the optimization of building materials to improve their thermal performance and mechanical properties. By doing so, we can minimize energy consumption, reduce carbon footprints, and move closer to realizing the principles of sustainable development. The construction industry has long been a significant contributor to global carbon emissions, with traditional cement and concrete production processes being especially harmful to the environment [3]. These materials account for a large percentage of industrial carbon dioxide emissions due to the energy-intensive processes required for their production. The calcination of limestone during cement production is particularly notable for its high energy consumption and the release of greenhouse gases [4]. Given the scale of global construction activities, reducing the environmental impact of

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building materials has become a critical objective.

Research efforts have increasingly turned toward the use of industrial and agricultural waste byproducts as substitutes or additives in cement and mortar formulations. These waste materials, often available in abundance and typically underutilized, present an opportunity to create more sustainable building materials. Rice husk ash (RHA) and bagasse ash (BA) are two such agricultural waste products that have shown promise as partial replacements for conventional components in mortar and concrete. Both materials are generated as byproducts of agricultural processing and are often disposed of in ways that contribute to environmental degradation [5, 6]. By incorporating RHA and BA into construction materials, it is possible to divert these wastes from landfills and incineration, while also reducing the need for virgin raw materials.

Rice husk ash is derived from the controlled burning of rice husks, which are the outer coverings of rice grains. When burned under appropriate conditions, rice husks produce ash that is rich in silica, making it a suitable pozzolanic material. Pozzolanic materials are substances that, when combined with lime or cement, undergo a chemical reaction to form compounds with cementitious properties [7]. This makes RHA a valuable additive for enhancing the strength and durability of mortar and concrete. Similarly, bagasse ash, produced from the combustion of sugarcane waste, contains silica and alumina, which also contribute to its pozzolanic activity [8]. Studies have shown that the addition of these ashes to cementitious materials can lead to improvements in mechanical properties, such as compressive strength, as well as reductions in thermal conductivity [9-11].

In recent years, geopolymer mortars have emerged as a potential alternative to traditional Portland cement-based mortars. Geopolymers are inorganic polymers formed by the reaction of an aluminosilicate source (such as fly ash or metakaolin) with an alkaline activator, typically sodium or potassium silicate [12]. Unlike Portland cement, which relies on the calcination of limestone, geopolymers can be produced at lower temperatures and with less energy, resulting in significantly lower carbon emissions. The incorporation of agricultural waste materials like RHA and BA into geopolymer mortars offers the potential to further enhance their environmental benefits, while also improving their performance in terms of thermal insulation and mechanical strength [13-15].

Several studies have investigated the thermal and mechanical properties of mortars incorporating agricultural waste materials. For example, a study by Nassar et al. [2] explored the use of RHA in geopolymer mixtures, demonstrating that the addition of RHA can improve the compressive strength of the material, while also reducing its thermal conductivity. Similarly, research by Handayani et. al. [3] examined the synthesis of sodium silicate from RHA as an activator for fly ash-based geopolymer mortars. The results showed that the use of RHA-derived sodium silicate led to improved mechanical properties, as well as enhanced thermal performance. These findings suggest that agricultural waste materials can play a key role in the development of more sustainable construction materials.

In addition to the use of agricultural waste materials, other studies have explored the incorporation of industrial byproducts into mortar and concrete. For example, Alvee et. al. [4] examined the effects of nano-silica and crystalline admixtures on the mechanical properties of geopolymer pastes. The results indicated that the addition of these materials led to significant improvements in strength and durability, making them suitable for applications where enhanced performance is required. Similarly, Arachchi et al. investigated the use of bottom ash (BA) as a substitute for sand in mortar mixtures [6]. The study found that the substitution of BA led to a substantial reduction in thermal conductivity, making the material more energy-efficient for building applications.

The potential benefits of incorporating agricultural waste materials into building materials extend beyond thermal and mechanical performance [16, 17]. By reducing the reliance on traditional raw materials, such as Portland cement and virgin aggregates, these alternative materials can help to conserve natural resources and minimize environmental impacts. Moreover, the use of waste materials in construction aligns with the principles of the circular economy, which aims to reduce waste, promote resource efficiency, and close material loops [18].

Despite the promising results of these studies, challenges remain in optimizing the use of agricultural waste materials in mortar and concrete [19]. One challenge is ensuring the consistency and quality of the waste materials, as variations in their chemical composition can affect the properties of the final product. For example, the silica content of RHA can vary depending on the burning conditions used during its production [22-22]. Similarly, the composition of BA can be influenced by factors such as the type of sugarcane processed and the combustion conditions. Addressing these variations requires careful control of the production processes and the development of standardized guidelines for the use of these materials [23-26].

Another challenge is balancing the performance of the material with its environmental benefits. While the use of agricultural waste materials can reduce carbon emissions and promote sustainability, it is important to ensure that the resulting mortar or concrete meets the necessary performance standards for strength, durability, and thermal insulation. Achieving this balance requires further research into the optimal mix designs, processing techniques, and applications for these materials.

In this paper, we report the results of an experimental investigation into the thermal and mechanical properties of mortars incorporating agricultural waste materials, specifically rice husk ash (RHA) and bagasse ash (BA). The study evaluates the thermal conductivity, compressive strength, and shrinkage characteristics of mortars with varying proportions of RHA and BA, both in conventional Portland Pozzolana Cement (PPC) mortars and in geopolymer mortars. The findings highlight the potential of RHA and BA to improve the sustainability and performance of construction materials, offering a viable alternative to

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traditional cement-based products. This research contributes to the growing body of literature on sustainable building materials and provides valuable insights for the development of more environmentally friendly construction practices.

2. EXPERIMENTAL DETAILS

Rice husk is an agricultural by-product obtained during the harvesting of rice grains from paddy fields. It is produced in large quantities worldwide as a result of milling paddy rice. One of the key components of rice husk is amorphous silica, which is present in significant amounts. On an industrial scale, silica is extracted from rice husk, though only a small fraction is typically utilized for this purpose [21]. India, being one of the largest sugarcane producers in the world, generates approximately 300 million tonnes of sugarcane annually [22]. A portion of the bagasse, a by-product of sugarcane processing, is used as fuel at sugar mills and also serves as a pozzolanic material in cement paste [23]. Fly ash is commonly used as a supplementary cementitious material in Portland cement concrete. When combined with Portland cement, fly ash can modify the properties of hardened concrete through either pozzolanic or hydraulic activity, or both, thereby improving the overall performance of the concrete [24].

The use of agricultural waste materials in the production of geopolymer mortars and concretes has gained significant attention due to its potential to reduce environmental impact and enhance sustainability. Geopolymers, which are inorganic polymers formed by the reaction of aluminosilicate minerals with alkaline activators, offer a promising alternative to traditional Portland cement. The primary objective of this study is to assess the feasibility of using agricultural waste as an insulation material in construction. To achieve this, mortar mixtures were cast instead of concrete to evaluate various mechanical properties. The mortar mix design maintained a cement-to-sand ratio of 1:3.

To investigate the mechanical properties, twelve distinct batches of mortar were prepared. The composite was cast into cubes (50 x 50 x 50 mm) using plastic molds, as shown in Figure 1. The sand was partially replaced by agro-waste at varying proportions of 0%, 5%, 15%, 30%, and 50% by weight, based on insights from the literature review. The cast cubes were cured under controlled laboratory conditions at a temperature of 28°C for a period of 28 days, as depicted in Figure 2. Table 1 presents the agro-waste replacement percentages along with their respective sample codes.

For geopolymer-based mortars, the same mold size of 50 x 50 x 50 mm was used. The geopolymer paste was produced by combining different proportions of alkaline activators, specifically sodium hydroxide and sodium silicate, as shown in Table 2. The geopolymer paste was then mixed with fly ash to produce mortar blocks, with 30% of the fly ash being replaced by rice husk ash and bagasse ash. The resulting geopolymer blocks are shown in Figure 3.

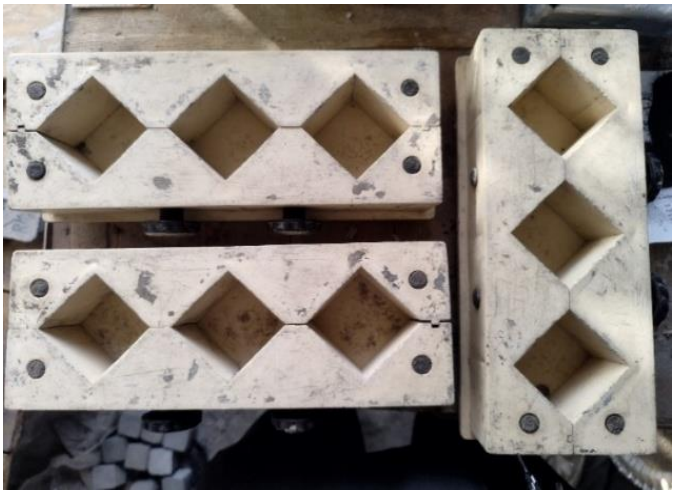

Fig. 1. Plastic moulds for preparation of samples.



Fig. 2. Cement based mortar dipped in water for curing.



Fig. 3. Geopolymer mortar in which fly ash replaced 30% by weight with RHA and BA.

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Table 1. Quantity of cement, sand and agricultural wastes used in mortars.

Agro waste	Mix no	No of cubes (50 x 50 x 50) mm^3	Cement by weight in grams	Sand by weight In grams	Agricultural waste replacement by % weight of sand	Agricultural waste weight in grams
PPC	M	12	1000	3000	0	0
Rice Husk Ash	R5	12	1000	2850	5	150
	R15	12	1000	2550	15	450
	R30	12	1000	2100	30	900
	R50	12	1000	1500	50	1500
Bagasse Ash	BA5	12	1000	2850	5	150
	BA15	12	1000	2550	15	450
	BA30	12	1000	2100	30	900
	BA50	12	1000	1500	50	1500

Table 1. Quantity of NAOH, Na_2Sio_3 and agricultural wastes used for Geopolymer mortars.

Mix ID	Mix no	No of cubes (50X50X50) mm^3	NAOH Pellets (gm)	Na_2Sio_3 (gm)	% Na_2O activator	%SiO_2 activator	Agri-waste 30% of fly-ash replacement By weight	Water (ml)	Fly ash Amount in gm	Agri-waste amount in gm
FA1	Fly Ash	10	96	406	6	6	0	235	1620	0
RH1	Rice husk	10	96	406	6	6	30	235	1134	486
BA1	Bagasse	10	96	406	6	6	30	235	1134	486
FA2	Fly Ash	10	90	475	6	7	0	193	1620	0
RH2	Rice husk	10	90	475	6	7	30	193	1134	486
BA2	Bagasse	10	90	475	6	7	30	193	1134	486
FA3	Fly Ash	10	84	543	6	8	0	150	1620	0
RH3	Rice husk	10	84	543	6	8	30	150	1134	486
BA3	Bagasse	10	84	543	6	8	30	150	1134	486
FA4	Fly Ash	10	120	408	7	6	0	231	1620	0
RH4	Rice husk	10	120	408	7	6	30	231	1134	486
BA4	Bagasse	10	120	408	7	6	30	231	1134	486
FA5	Fly Ash	10	114	475	7	7	0	187	1620	0
RH5	Rice husk	10	114	475	7	7	30	187	1134	486
BA5	Bagasse	10	114	475	7	7	30	187	1134	486
FA6	Fly Ash	10	106	543	7	8	0	145	1620	0
RH6	Rice husk	10	106	543	7	8	30	145	1134	486
BA6	Bagasse	10	106	543	7	8	30	145	1134	486
FA7	Fly Ash	10	144	408	8	6	0	225	1620	0
RH7	Rice husk	10	144	408	8	6	30	225	1134	486
BA7	Bagasse	10	144	408	8	6	30	225	1134	486
FA8	Fly Ash	10	137	475	8	7	0	183	1620	0
RH8	Rice husk	10	137	475	8	7	30	183	1134	486
BA8	Bagasse	10	137	475	8	7	30	183	1134	486
FA9	Fly Ash	10	129	543	8	8	0	140	1620	0
RH9	Rice husk	10	129	543	8	8	30	140	1134	486
BA9	Bagasse	10	129	543	8	8	30	140	1134	486

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3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Compressive Strength

The compressive strength of the mortar samples was determined according to IS 4031 Part 6, which provides the standard procedure for evaluating the compressive strength of cement mortars. The mix used for testing consisted of three parts sand to one part cement by weight. The mould was carefully lubricated to ensure easy removal of the samples, as depicted in Figure 1. Following the preparation and curing of the samples, compressive strength was tested using a Compressive Testing Machine (CTM). The formula for calculating the cube's compressive strength:

$$F=P/A \quad (1)$$

A is the surface area exposed to the machine block in mm^2, P is the total load applied in Newtons (N), and F is the compressive strength in MPa.

The compressive strength results for Rice Husk Ash-based mortar samples, which replaced sand by 5%, 15%, 30%, and 50%, were 29 N/mm², 28 N/mm², 22 N/mm², and 15 N/mm², respectively. For Bagasse Ash-based mortars, the samples showed compressive strengths of 32 N/mm², 30 N/mm², 23 N/mm², and 14 N/mm², corresponding to 5%, 15%, 30%, and 50% sand replacement. This suggests that as the replacement percentage increased, the compressive strength decreased, with Bagasse Ash showing slightly better strength than Rice Husk Ash.

Geopolymer-based mortars using Fly Ash demonstrated superior strength compared to conventional mortar. Mix 7, which incorporated Fly Ash, exhibited compressive strengths of 27 N/mm², 32 N/mm², and 42 N/mm² at 7, 14, and 28 days, respectively. The use of Rice Husk Ash in the geopolymer mix slightly increased the strength, whereas the use of Bagasse Ash showed a slight decrease in strength.

3.3.2 Water Absorption Test

The water absorption capacity of the mortars was determined using the oven drying method. The average water content for the standard cement mortar was found to be 3.2%. For Rice Husk Ash-based mortars, with sand replacements of 5%, 15%, 30%, and 50%, the water absorption increased initially to 5.9% and then decreased to 3.5%. Bagasse Ash-based mortars displayed a similar trend in water absorption. The moisture content is calculated using the following formula:

$$\%\ W = \frac{(W_w - W_d)\times 100}{W_w} \quad (2)$$

Where, $\%\ W$ = percentage water content,
W_d= Weight of oven dried mortar block at 100 ^{O}C after 24 hrs
W_w= Weight of wet mortar submerged in water for 24 hours,

Geopolymer mortars, particularly Mix 7, which showed the highest compressive strength, also exhibited lower water absorption. This reduction in water content is likely due to the higher concentration of NaOH in the alkaline solution used for the geopolymer mortars. The mortars containing Rice Husk Ash and Bagasse Ash showed similar water absorption trends, consistent with findings reported by Tenepalli (2018) [25, 26], which indicated that higher NaOH concentrations generally reduce water absorption in fly ash-based geopolymer mortars.

3.3.3 Linear Shrinkage Test

Linear shrinkage was evaluated based on the method outlined in ASTM C113 [25]. Rice Husk Ash-based mortars showed minimal shrinkage at 5% and 15% sand replacement, similar to the standard 1:3 cement-sand mortars. However, as the replacement increased to 30% and 50%, the linear shrinkage values increased significantly. Bagasse Ash-based mortars exhibited a similar pattern, with shrinkage values increasing at higher replacement percentages. The cube's linear shrinkage is computed as follows:

$$S = \frac{(L_1 - L_2)\times 100}{L_1} \quad (3)$$

Where, S = Linear Shrinkage in percentage, L_1 = Initial dimension of mortar block, and L_2= Final dimension after heating at 700 degrees Celsius.

This suggests that while smaller amounts of agricultural waste can be incorporated into mortar without significantly affecting shrinkage, higher percentages may lead to increased dimensional changes, potentially compromising the integrity of the material.

3.3.4. Thermal Conductivity Analysis

The thermal conductivity of the mortar samples was evaluated by applying a constant heat of 60°C to one face of the mortar wall and measuring the temperature on the opposite face using temperature sensors. Regular cement-sand mortar (1:3 ratio) exhibited the highest thermal conductivity. However, the thermal conductivity slightly decreased in Rice Husk Ash-based mortars with 5% and 15% sand replacement. Similarly, Bagasse Ash-based mortars showed slightly lower heat transfer compared to regular mortar, with 5% and 15% sand replacements yielding lower conductivity values.

For geopolymer mortars, particularly Mix 7, which had the highest compressive strength, the thermal conductivity was measured after exposing the mortar block to constant heat. The fly ash-based geopolymer mortar demonstrated the highest thermal conductivity among the samples. When 30% of the fly ash was replaced by Rice Husk Ash or Bagasse Ash, the thermal conductivity decreased, but the fly ash-based

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sample still retained higher conductivity than the others.

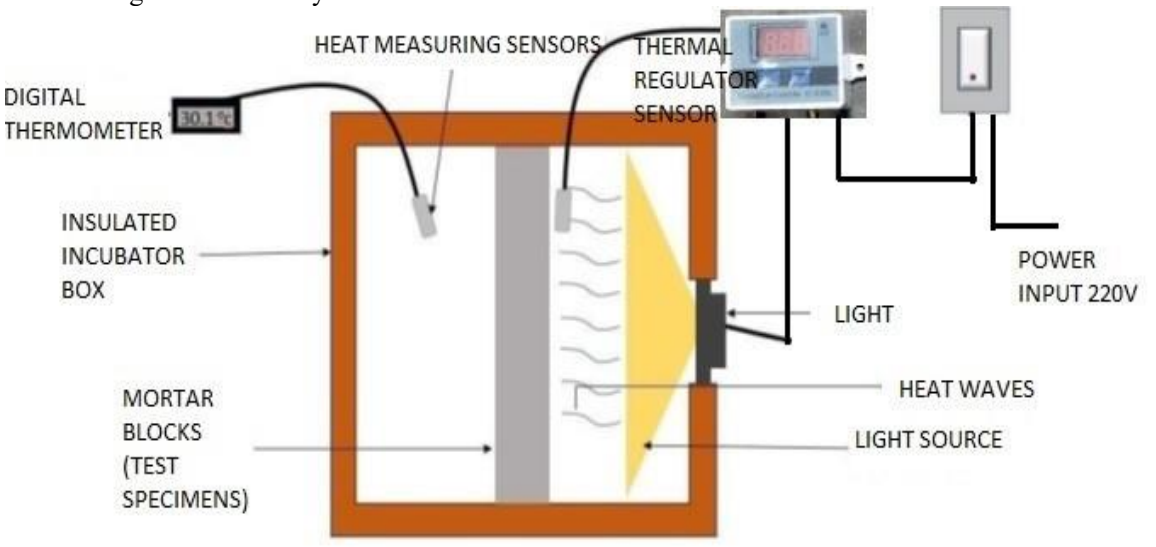

Fig. 4. Connection diagram of the sensor for continuous regulation of heat.

This indicates that fly ash contributes significantly to both compressive strength and thermal performance in geopolymer mortars.

Figure 4 illustrates the movement of a heat wave (one-dimensional heat flow) from one side of a homogeneous solid layer to the other. As is demonstrated. This time-domain transient process depends heavily on the geometry and thermo-physical characteristics of the material layers. The parameters define the thermal resistance and capacitance of this heat flow.

The input power of 250 watts with 220 volts have been provided through the Thermal Regulator Sensor for maintaining the constant temperature of 60 ^{O}C at the side of mortar wall so that the heat from one side of mortar conducts to the other side. The record of temperature conduction thought the mortar walls have been taken at every interval of hours by using 3 temperature sensors. Once the temperature at the thermal regulator sensor side reaches above 60 ^{O}C by glowing two bulbs thus generating heat, the relay assembly in the sensors cuts the power and once heat losses and temperature falls below the 60 ^{O}C then the Thermal Regulator Sensor switches on and same process repeats again and again till 4 hours. The conduction of heat from the mortar wall is recorded by average of 3 temperature sensors shown front side in Figure 5.

3.2. Discussion

The strength analysis of Rice Husk Ash (RHA) based samples revealed a notable variation in compressive strength, with values of 29 N/mm² for 5% sand replacement, 28 N/mm² for 15%, 22 N/mm² for 30%, and a significant drop to 15 N/mm² for 50% replacement. This trend suggests that low levels of RHA incorporation provide sufficient bonding and cohesion in the mortar, likely due to its high silica content. However, at higher replacements, the particle size and shape of RHA may interfere with the compactness and hydration process, leading to a reduction in strength. Similarly, Bagasse Ash (BA) showed a consistent decline in strength with increased replacement levels, yielding 32 N/mm² at 5%, 30 N/mm² at 15%, 23 N/mm² at 30%, and 14 N/mm² at 50%. The slightly higher initial values of BA-based mortars compared to RHA can be attributed to its distinct chemical composition and reactive silica content, which may enhance early-age strength but diminish with excessive ash content due to the dilution of cementitious material.



Fig. 5. Isometric view of thermal conductivity testing arrangement.

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The geopolymer paste-based mortars exhibited superior compressive strength, with Fly Ash-based Geopolymer mix 7 achieving compressive strengths of 27 N/mm², 32 N/mm², and 42 N/mm² at 7, 14, and 28 days, respectively. The increase in strength over time can be associated with the progressive geopolymerization process, wherein fly ash reacts with the alkaline activator (NaOH) to form a dense aluminosilicate network. This contrasts with Rice Husk Ash and Bagasse Ash, where strength gains are slower, and the maximum strengths achieved are comparatively lower. The slight increase in compressive strength for RHA-based geopolymer mortars and the marginal decrease in BA-based mortars may indicate the varying reactivity of these ashes in geopolymeric systems, possibly due to differences in their silica and carbon content, affecting the formation of the geopolymer matrix.

Water absorption tests provided additional insights into the porosity and microstructure of the mortars. The cement-based mortars exhibited an average water content of 3.2%, while RHA-based mortars showed an initial rise to 5.9% at 5% replacement, followed by a reduction to 3.5% at higher replacement levels. This behavior suggests that RHA contributes to increased porosity at lower replacement levels but eventually aids in filling voids and refining the pore structure as the ash content increases. A similar trend was observed in BA-based mortars, indicating that both ashes have a complex influence on the water absorption characteristics, potentially due to the interplay between pore structure refinement and the ash's inherent hydrophobicity.

Geopolymer mortars, particularly mix 7, demonstrated the lowest water absorption values, consistent with the findings of J.S. Tenepalli (2018), who reported reduced water absorption in fly ash-based geopolymer mortars due to the higher concentration of NaOH. The reduced porosity in these geopolymer mortars can be attributed to the formation of a more compact matrix, which minimizes water penetration. The behavior of RHA- and BA-based geopolymer mortars mirrored that of the traditional mortar systems, with slightly higher water absorption levels compared to the fly ash-based geopolymer mixes, likely due to incomplete geopolymerization or the presence of unreacted particles in the mix.

The linear shrinkage results highlighted that RHA-based cement mortars at 5% and 15% replacement levels exhibited shrinkage values comparable to standard 1:3 cement-sand mortars. However, the shrinkage values increased significantly at 30% and 50% replacement, likely due to the reduced cement content and the higher shrinkage potential of RHA at elevated dosages. Similar trends were observed in BA-based mortars, further supporting the notion that the ash content beyond a certain threshold disrupts the structural integrity of the mortar, leading to excessive shrinkage.

Thermal conductivity analysis showed that mortar blocks with optimal compressive strength exhibited distinctive thermal performance. At room temperature (25°C), traditional 1:3 cement-sand mortars exhibited the highest thermal conductivity when exposed to a constant heat of 60°C, as recorded over four hours using temperature sensors. The thermal conductivity of RHA-based mortars decreased slightly with 5% and 15% sand replacement, suggesting that the ash content contributed to reduced heat transfer due to its insulating properties. BA-based mortars also demonstrated a reduction in thermal conductivity, but the effect was more pronounced than in RHA-based mortars, indicating that the porous structure of BA may offer better thermal insulation.

The fly ash-based geopolymer mortars from mix 7, which exhibited the highest compressive strength, also showed higher thermal conductivity compared to RHA and BA-based mortars when subjected to the same thermal conditions. This can be explained by the dense, cohesive structure of geopolymer mortars, which promotes heat conduction more efficiently than mortars with higher ash content. The increased thermal conductivity in fly ash-based geopolymer mortars may be advantageous in applications requiring efficient heat dissipation, though it may pose challenges for energy-efficient designs.

4. CONCLUSION

The experimental investigation demonstrates that incorporating agro-waste materials such as Rice Husk Ash (RHA) and Bagasse Ash (BA) into mortar compositions leads to a steady reduction in thermal conductivity, with RHA (at 15% sand replacement) outperforming conventional Portland Pozzolana Cement (PPC) mortar by reducing heat conductivity by 19°C in 4 hours, and BA by up to 17°C. The reduction in thermal conductivity confirms the potential of agro-waste additives in improving the thermal insulation properties of mortars. For geopolymer mortars, the Fly Ash-based mix (Mix 7) showed superior strength, but when Rice Husk Ash (RA7) and Bagasse Ash (BA7) were used, they further reduced heat conductivity by 12°C and 14°C, respectively, compared to the Fly Ash-based mortar. These results highlight the efficiency of agro-waste in enhancing thermal performance even in geopolymer matrices. A notable reduction in linear shrinkage was observed across all compositions with increasing agro-waste content, with Bagasse Ash-based mortars showing minimal shrinkage at a 5% sand replacement. Strength analysis revealed that Bagasse Ash at 5% and 15% replacement levels was the most effective in enhancing the strength of PPC-based mortars. Among the geopolymer mortars, Mix 7 exhibited the best compressive strength, further affirming its suitability for applications requiring high-strength materials with improved thermal and shrinkage properties. Overall, the use of agro-waste materials such as Rice Husk Ash and Bagasse Ash in both conventional and geopolymer mortars offers promising benefits, including enhanced thermal insulation, reduced shrinkage, and improved mechanical properties, making them viable alternatives in sustainable construction practices.

CONFLICT OF INTEREST

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The authors declare that there is no conflict of interests.

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