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Research article

A Simple Thermal Curing Method to Produce Non-load-Bearing LAC with Sand Partially Replaced by Rice Husk Ash

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Abstract: This study presents an investigation into the production of non-load-bearing Lightweight Aggregate Concrete (LAC) with sand partially replaced by rice husk ash (RHA) using a simple thermal curing process. This method aims to simplify the production process, eliminating the need for expensive machinery and complex procedures, while significantly reducing curing time. Sand was replaced at 10%, 20%. 30%, 40%, and 50% mass ratios . The RHA, cement, and water are first mixed, then lime and gypsum powder are added and mixed. Aluminum powder was added once a homogeneous blend was obtained. The mix is poured into concrete molds, and air bubbles are removed to ensure material compactness. The specimens are left to stabilize for 12 hours, cured at 60°C for 6 hours, and then placed in desiccators for 1 hour to allow moisture equilibration. Subsequently, the bricks undergo a second heat treatment at elevated temperatures of 150°C and 180°C for 12 hours. The physical characteristics of the resulting LAC were analyzed using Scanning Electron Microscopy (SEM), Energy-Dispersive X-ray Spectroscopy (EDX), and X-ray Diffraction (XRD). The results confirmed that the LAC exhibits geopolymeric behavior, with the presence of silicon oxide as a key component. Specimens analyzed using SEM and XRD revealed the formation of compounds that contribute to concrete strength, including calcium carbonate, silicon oxide, calcium hydroxide, and potassium oxide. The compressive strength of all mixes met ASTM C129-06, with the highest value of 16.95 MPa observed at 30 % RHA. Thermal curing at 150°C was also found sufficient. The proposed method and 50% RHA offer significant advantages in reducing production costs, curing time, and helping preserve natural sand resources. This approach enables communities and small-scale industries to produce LAC, supporting sustainable construction practices and local economic development.

Keywords: Rice husk ash; lightweight aggregate concrete; geopolymer

1. Introduction

Thailand has implemented strict regulations on sand mining due to the declining availability of high-silica sand. In 2022, the export of sand containing more than 75% silicon dioxide (SiO_2) was officially prohibited. According to data from the Department of Foreign Trade [1], Thailand exports approximately 885,110 tons of sand annually, with an average income of 17.46 million (~33 baht = 1 USD). In contrast, the country imported up to 1,817,029 tons of sand, valued at over 1.326 billion baht. The increasing demand for sand has led to intensified

mining activities and the search for new river sand sources, resulting in significant environmental degradation, particularly the erosion of natural riverbanks. River sand is particularly valued for its silica (SiO_2) content, making it one of the most extensively mined mineral resources globally. Thai river sand exhibits a range of morphological characteristics, including both angular and rounded particles [2], with particle sizes ranging from 20 to 200 mesh. In 2022, Thailand produced approximately 35.5 million tons of rice a year, resulting in a substantial quantity of rice husks, which were subsequently incinerated for energy generation. Upon complete combustion, Rice Husk Ash (RHA) is produced [3]. The yield of RHA is estimated to be around 20–25 kilograms per ton of burned husk. RHA typically appears as a fine powder in shades of grey, white, or black, depending on the combustion method and temperature. It is lightweight and easily dispersed as airborne particles and is considered a significant industrial waste due to its large volume. As RHA is primarily composed of silica (SiO_2), which exists in both amorphous and crystalline forms [4, 5], it has been incorporated into construction materials and revealed its potential as a precursor for geopolymer synthesis, particularly when subjected to thermal activation. RHA has been widely studied for its effects on physico-mechanical properties, durability, and microstructure.[6]

Non-load-bearing Lightweight Aggregate Concrete (LAC) is primarily used as partition walls in buildings, serving as thermal insulation. Its key characteristics include light weight and minimal structural strength requirements, as it is not intended to bear significant loads. This type of concrete benefits from the advantageous properties of RHA when used as a partial replacement for conventional aggregates. The finer particle size and spherical morphology of RHA, compared to sand, contribute to improved density and uniformity in the concrete matrix, reducing voids and minimizing the risk of cracking. Additionally, RHA facilitates faster production when thermal curing is applied, as it promotes the formation of geopolymer gel structures. When the aggregate is sufficiently fine and mixed with water, it reacts with calcium hydroxide to form strong bonds, enhancing the flowability and cohesion of the concrete mixture [7, 8]. In large-scale lightweight concrete industries, porosity is typically induced through autoclaving under steam pressure. However, this method requires specialized steam-curing equipment, which remains limited in Thailand due to its high cost. As a result, small-scale and community-based industries often lack access to such production technologies. Noman et al. found [9] that thermal curing of geopolymer concrete can achieve adequate early strength and even outperform conventional steam-cured concrete. Elevated curing temperatures accelerate water evaporation, which reduces the workability of cement paste but simultaneously shortens the setting time and enhances early strength development [10]. Ilić et al. [11] reported that reducing the curing time can yield comparable strength to 28-day curing, thereby offering potential advantages in terms of reduced production time and faster product delivery.

The objective of this study is to develop a simplified production method to produce low-cost, non-load-bearing LAC with sand partially replaced by rice husk ash (RHA). The research focuses on identifying the optimal replacement ratio of RHA and analyzing the effects of accelerated thermal curing on the concrete's properties.

2. RHA and River sand properties

The RHA used in this study was sourced from a food processing industry located in Suphanburi Province, Thailand. The rice husks were incinerated using a closed combustion chamber at a temperature of 800 °C. The resulting ash exhibited moisture loss and appeared as a dark grey powder with a high degree of crystallinity [3], [4]. It has been reported that incineration temperatures ranging from 800 to 1200 °C result in a low Loss on Ignition (LOI), making the material suitable for use as a pozzolanic additive and a potential precursor for geopolymer synthesis [12]. To evaluate the potential of RHA as a partial replacement for river sand in the production of Lightweight Aggregate Concrete (LAC), we employed three non-destructive analytical techniques: X-ray Fluorescence (XRF), Energy Dispersive X-ray Spectroscopy (EDS), and X-ray Diffraction (XRD). Although each method operates on different principles, the combined use of these techniques provides complementary data that enhances the accuracy of chemical composition identification. These methods are widely adopted for comprehensive chemical characterization of materials [2, 4, 13]. Table 1 presents a comparative analysis of the chemical composition of river sand and rice husk ash (RHA) using X-

ray Fluorescence (XRF). The results revealed that the dominant component in both aggregates is silicon dioxide (SiO_2), with concentrations of approximately 77.98% and 79.72%, respectively. These findings are consistent with previous studies [3, 4].

Table 1. Comparison of Chemical Composition between River Sand and Rice Husk Ash (RHA) via XRF Analysis.

Formula	SiO_2	Al_2O_3	K_2O	Fe_2O_3	P_2O_5	MgO	TiO_2	MnO	CaO	SO_3
Sand	77.98%	10.26%	6.04%	2.35%	1.34%	0.36%	0.57%	0.02%	0.68%	0.12%
RHA	79.72%	0.58%	6.54%	1.17%	3.51%	0.58%	0.08%	0.28%	6.53%	0.65%

Figure 1 shows a comparative analysis of the amorphous characteristics (left) and Scanning Electron Microscopy SEM (right) between river sand and RHA. It reveals that RHA shows a dark ash appearance, and the amorphous phase is primarily located on the surface of the RHA particles, with a morphology that closely resembles that of the river sand.

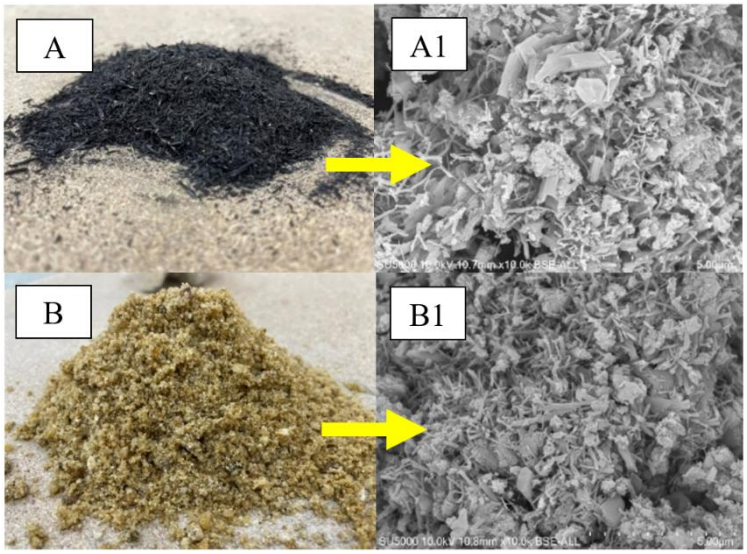


Figure 1. Photographs (left) of RHA after combustion at 800 °C (A) and river sand (B) and SEM images (right) magnified at 10000 of RHA (A1) and river sand (B1).

Figure 2 shows the results of XRD analysis (left) and elemental analysis performed using Energy Dispersive X-ray Spectroscopy (EDS/EDX) of RHA and river sand (right). Figures 2 (C) and 2 (D) confirm the crystalline structure of SiO_2, which is in accord with published data [13]. EDS/EDX analysis indicates that both RHA (C1) and river sand (D1) contain silicon (Si) as a major component. The oxygen-to-silicon (O: Si) ratio was approximately 1.18 for RHA and 1.54 for river sand, suggesting that silicon dioxide (SiO_2), commonly referred to as silica, is the predominant compound in both materials. Additionally, aluminum (Al) was detected, which plays a key role in geopolymer formation.

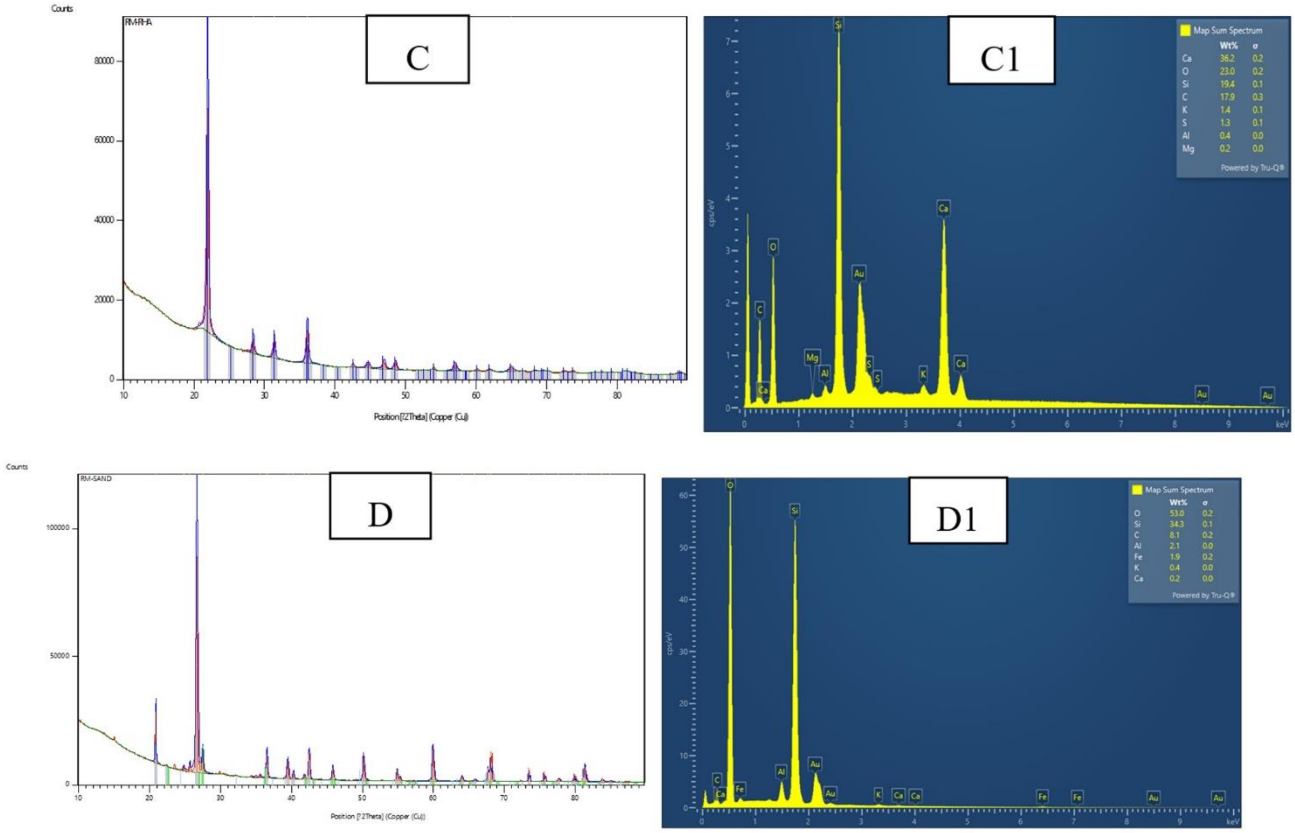


Figure 2. XRD analysis (left) of RHA (C) and river sand (D) and SEM -EDX analysis (right) of RHA (C1) and river sand (D1).

Elemental mapping of carbon (C), silicon (Si), aluminum (Al), and oxygen (O) of RHA (a2) and river sand (b2) using EDS is shown in Figure 3. It reveals that river sand exhibits a uniform distribution of C, Si, Al, and O, with Si and O being the dominant elements. In contrast, RHA shows a relatively even distribution of C, Si, and O throughout the sample, while Al appears in lower concentrations and was either undetected or minimally detected in the EDS mapping. Based on the O: Si ratio and elemental distribution, the SiO_2 content in RHA is comparable to that of river sand, with a consistent dispersion throughout the sample.

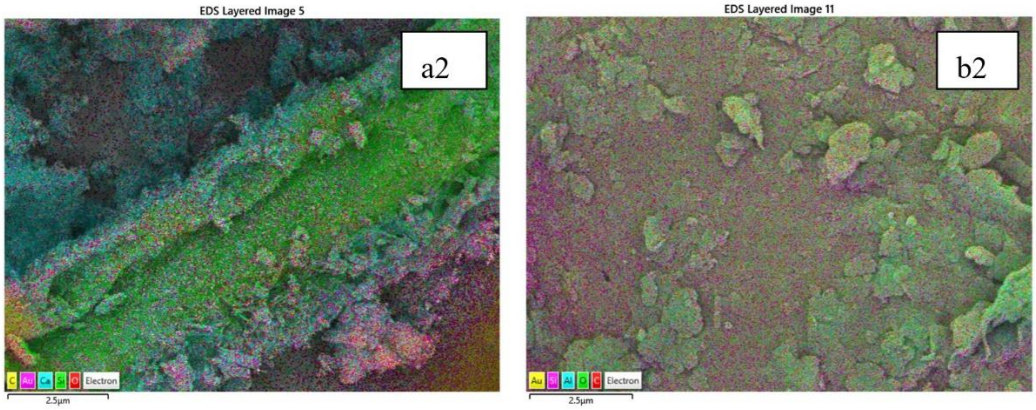


Figure 3. Elemental mapping of C, Si, Al, and O using Energy Dispersive X-ray Spectroscopy (EDS): (a2): RHA; (b2): River sand.

Furthermore, XRD analysis of RHA revealed diffraction planes indicative of the crystalline nature of SiO_2. The presence of broad band peaks in the XRD pattern also suggests a significant amorphous phase within the sample, reflecting structural irregularities. These findings are consistent with the study reported

in Xu et al. [14]. The amorphous characteristics of RHA support its classification as a pozzolanic material and a potential precursor for geopolymer synthesis. When subjected to elevated temperatures during concrete formation, RHA has the potential to initiate the formation of geopolymer gel, thereby enhancing the mechanical strength of the resulting polymer concrete. These results confirm that RHA with similar particle morphology to river sand can serve as a viable substitute for river sand in terms of silica content in concrete applications.

3. Production process

The production process of geopolymer-based bricks differs from that of conventional cement-based materials, particularly in the second stage, which involves the application of thermal energy (heat curing of concrete) as it can significantly influence the geopolymerization mechanism [9]. The raw materials we used include Portland cement, aluminum powder (Al), gypsum cement ($CaSO_4$), and lime (CaO), all of which are maintained at fixed proportions. The proposed manufacturing process is schematically shown in Figure 4. The initial step involves sieving sand and RHA to achieve uniform particle sizes and consistency in the raw materials prior to mixing, in accordance with ASTM C33–Standard Specification for Concrete Aggregates. The aggregates were passed through sieves in sequential mesh sizes of No. 4, 8, 16, 30, 50, and 100. Then the mixing process begins with sand, RHA, cement, and water using a concrete mixer. Next, lime and gypsum powder are added and mixed until a homogeneous blend is achieved; then aluminum powder is added. The chemical reaction between aluminum powder and cement initiates a pozzolanic reaction [15], resulting in the formation of a polymeric gel that can uniformly penetrate and bind throughout the LAC matrix. Hydrogen gas bubble generation begins approximately 30 minutes after mixing, creating porosity within the concrete matrix [16, 17]. The addition of gypsum and lime serves to retard the formation of calcium silicate hydrate (CSH), preventing premature hardening during the production process.

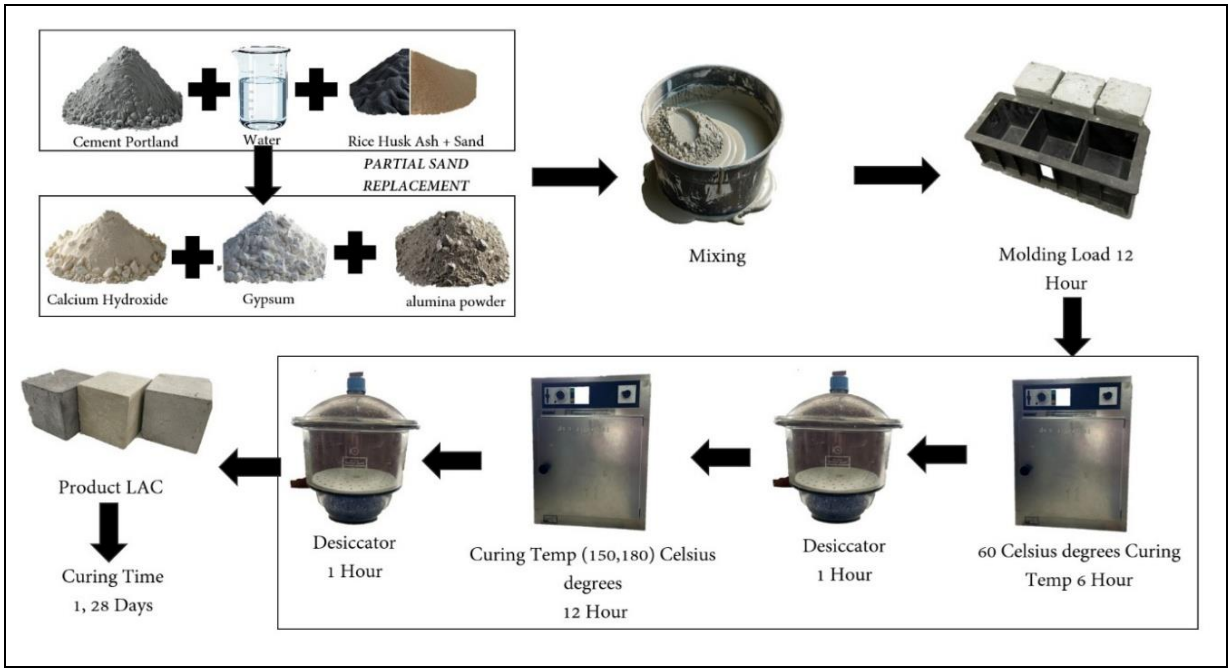


Figure 4. Production Process of non-load Lightweight Aggregate Bricks Using Rice Husk Ash as Partial Sand Replacement

Once the mix reaches uniform consistency, it is poured into concrete molds. During molding, the slurry is evenly distributed throughout the mold, and air bubbles are removed to ensure material compactness. The surface is then leveled, and the specimens are left to stabilize for 12 hours before demolding. The next phase involves heat treatment at 60°C for a duration of six hours, which facilitates the formation of aluminosilicate compounds with semi-crystalline structures, contributing to the hardening of the material and enhancing the mechanical strength of the resulting bricks as observed in Kljajević et al. [18], Rovnaník et al. [19].

After curing, the specimens are placed in desiccators for 1 hour to allow moisture equilibration. Subsequently, the bricks undergo a second thermal curing at elevated temperatures for 12 hours, followed by another 1-hour rest period in the desiccators. Two curing temperatures are considered, namely 150°C and 180°C. During this process, the formation of block-like tetrahedral crystalline structures was observed in agreement with the findings of Polat et al. [20] investigating the reaction between SiO_2 and Al_2O_3 in powdered alumina.

Table 2 summarizes the aggregate mixing ratio adopted. Portland cement, aluminum powder, calcium hydroxide, and gypsum are kept constant. The initial quantity of sand is 400 grams to be mixed to make the bricks. Five ratios for replacing sand were considered as follows: 10%, 20%, 30%, 40%, and 50% by weight. In all mixes, 400 grams of water were used, and five specimens were produced for each mixing ratio.

Table 2. Mixing Proportions ratios

Raw materials	Raw materials ratio (Unit grams)		
Cement	Constant 480		
Calcium Hydroxide	Constant 144		
Gypsum	Constant 145		
Aluminum Powder	Constant 32		
Specimens Composition	RHA ratio	Sand (Unit grams)	RHA (Unit grams)
	10%	360	40
	20%	320	80
	30%	280	120
	40%	240	160
	50%	200	200

4. Result discussions

4.1 Density and compressive strength

The density of specimens and compressive strength tests were conducted following ASTM C129-06 Standard Specification for Nonloadbearing Concrete Masonry Units [21], which is suitable for non-structural geopolymer concrete applications and widely adopted [22, 23]. The specimen with dimensions of 10 cm × 10 cm × 10 cm was placed at the center of the testing platform, ensuring that its axis was aligned with the center of the loading head and that the surface area of the specimen matched the dimensions of the loading plate. The compressive load was applied uniformly until the specimen failed. The maximum compressive force recorded at the point of failure was used to calculate the ultimate compressive strength, based on the load and the cross-sectional area of the specimen. Figure 5 summarizes the average density of all mixing ratios categorized by curing time and temperature. The results indicated that the density of all specimens was below 1680 kg/m^3, which is the maximum limit specified by ASTM C129-06 for nonloadbearing concrete applications.

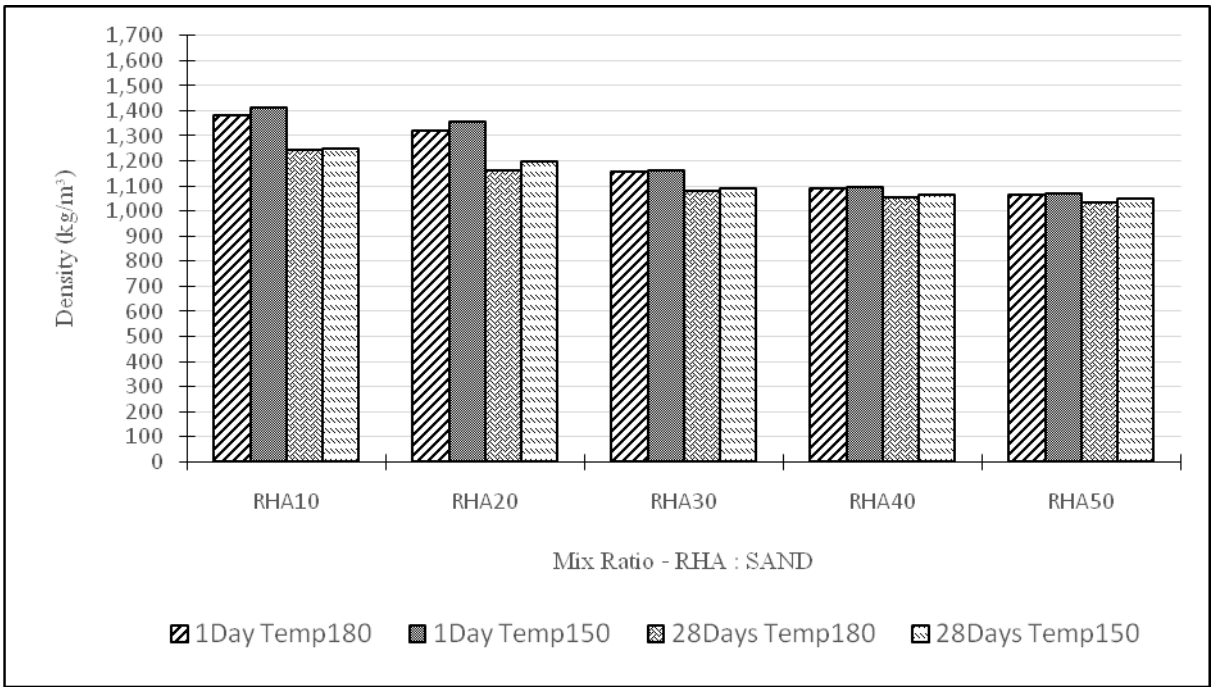


Figure 5. Density of specimens for the different mixing ratios categorized by curing time and temperature

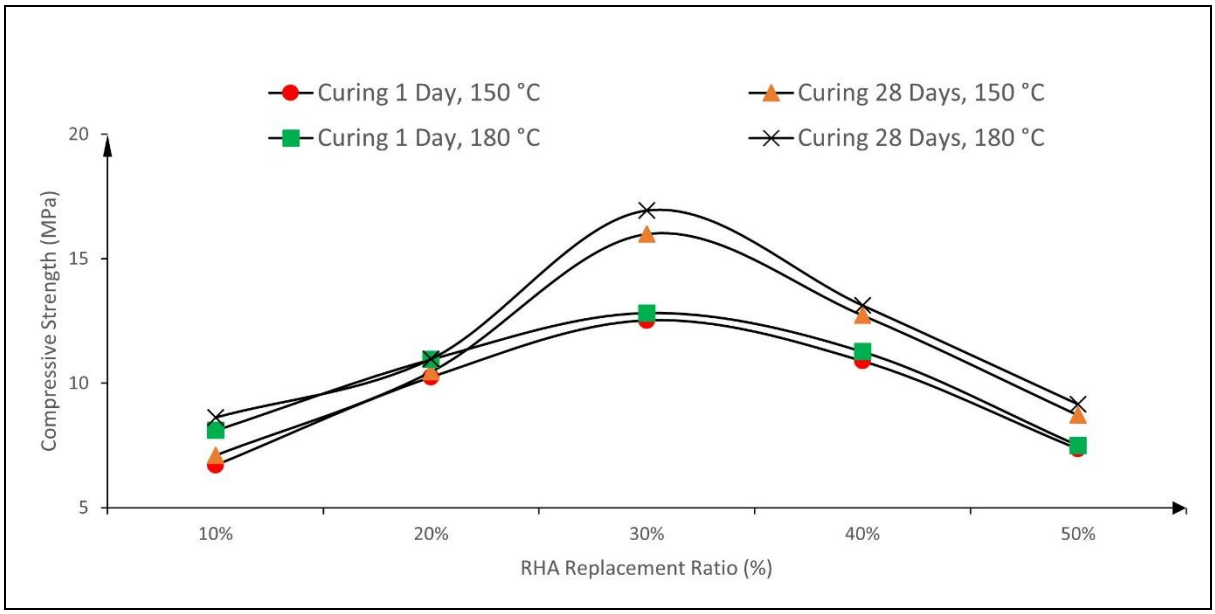


Figure 6. Average compressive strength versus RHA substitution ratio for different curing time and temperature.

Statistical analysis was performed using a one-way analysis of variance (ANOVA) followed by Tukey's multiple comparison test at a 95% confidence level ($p < 0.05$) in Minitab 21. The results indicated that both the mix ratios (10%, 20%, 30%, 40%, and 50%; $p = 0.000$) and curing periods (1 day and 28 days; $p = 0.002$) had a statistically significant effect on the compressive strength of the rice husk ash Lightweight Aggregate Bricks. In contrast, the thermal treatment temperature did not exhibit a significant effect ($p = 0.157$). Furthermore, Tukey's comparison revealed that the 30 % replacement ratio yielded the highest mean compressive strength, which was significantly distinct from the lower replacement levels.

Table 3 summarizes the average compressive strength of all mixing ratios categorized by curing time and temperature considered. It can be observed that longer curing time and higher temperature lead to

higher values. However, all mix proportions under the tested conditions successfully met or exceeded the minimum compressive strength requirement specified in ASTM C129-06, which states that nonloadbearing concrete masonry units must have a compressive strength greater than 4.14 MPa, confirming the structural viability of the lightweight aggregate concrete produced. Increasing the RHA ratio under all production scenarios increased compressive strength until an optimum was observed at 30% RHA, as shown in Figure 6; then it decreased considerably. Therefore, it can be concluded that 1-day curing duration and 150°C curing temperature with 50% RHA sand replacement ratio are acceptable to produce non-load LAC that reduces production time and saves costs significantly.

Table 3. Average Compressive Strength Test Results

Curing Time (Days)	Ratio	Compressive Strength (MPa)	
	RHA Replacement	At-150 (°C) Cure Temp	At-180 (°C) Cure Temp
1 Day	10%	7.04 ± 0.17	8.11 ± 0.66
	20%	10.62 ± 0.20	10.96 ± 0.21
	30%	12.74 ± 0.18	12.82 ± 0.94
	40%	10.89 ± 0.89	11.27 ± 0.43
	50%	7.36 ± 0.55	7.51 ± 0.59
28 Days	10%	7.11 ± 0.43	8.62 ± 0.31
	20%	10.47 ± 0.50	10.98 ± 0.27
	30%	16.00 ± 0.22	16.95 ± 0.28
	40%	12.73 ± 0.92	13.13 ± 0.31
	50%	8.72 ± 0.67	9.15 ± 0.52

4.2 Chemical Properties of Lightweight Aggregate Concrete (LAC)

To observe the surface morphology and microstructural development associated with the geopolymer gel formation, samples of the specimens were selected for chemical characterization using Scanning Electron Microscopy (SEM) at a magnification of 10,000×. The SEM images are presented in Figure 7 and organized according to the %RHA ratio for 1-day curing time at 150°C and 180°C. It was observed that the specimens exhibited stable structural formation. This confirms that thermal curing at low temperature can accelerate the gelation process, allowing the gel to uniformly penetrate and bind throughout the LAC matrix. The consolidation of the aggregate matrix occurred uniformly, and the formation process demonstrated a diffusion-based mechanism, indicating the development of geopolymeric behavior and gel reactions consistently across all experimental conditions.

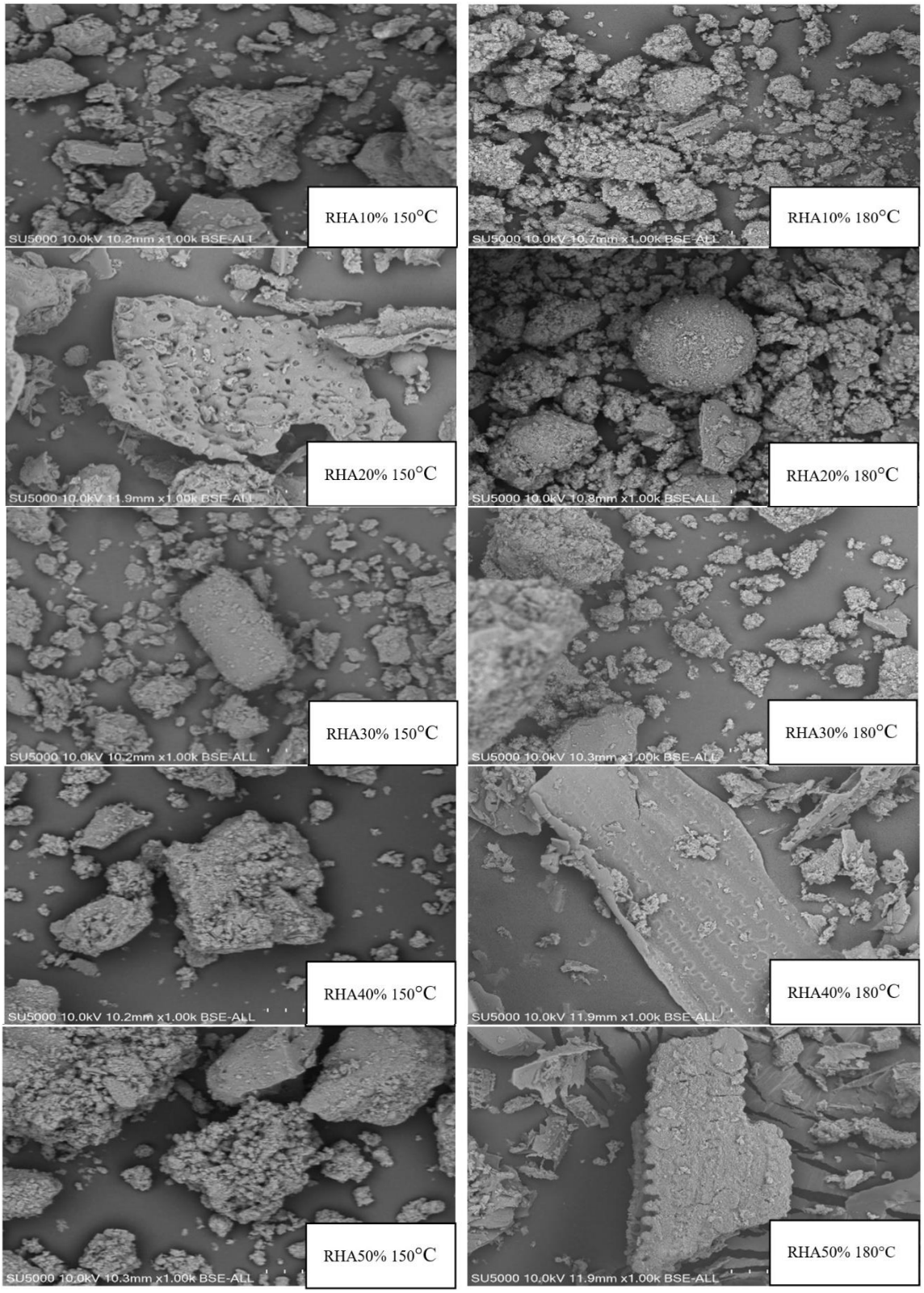


Figure 7. SEM images at 10,000× magnification of LAC specimens for different RHA ratios cured for 1 day at 150°C (left) and 180°C (right).

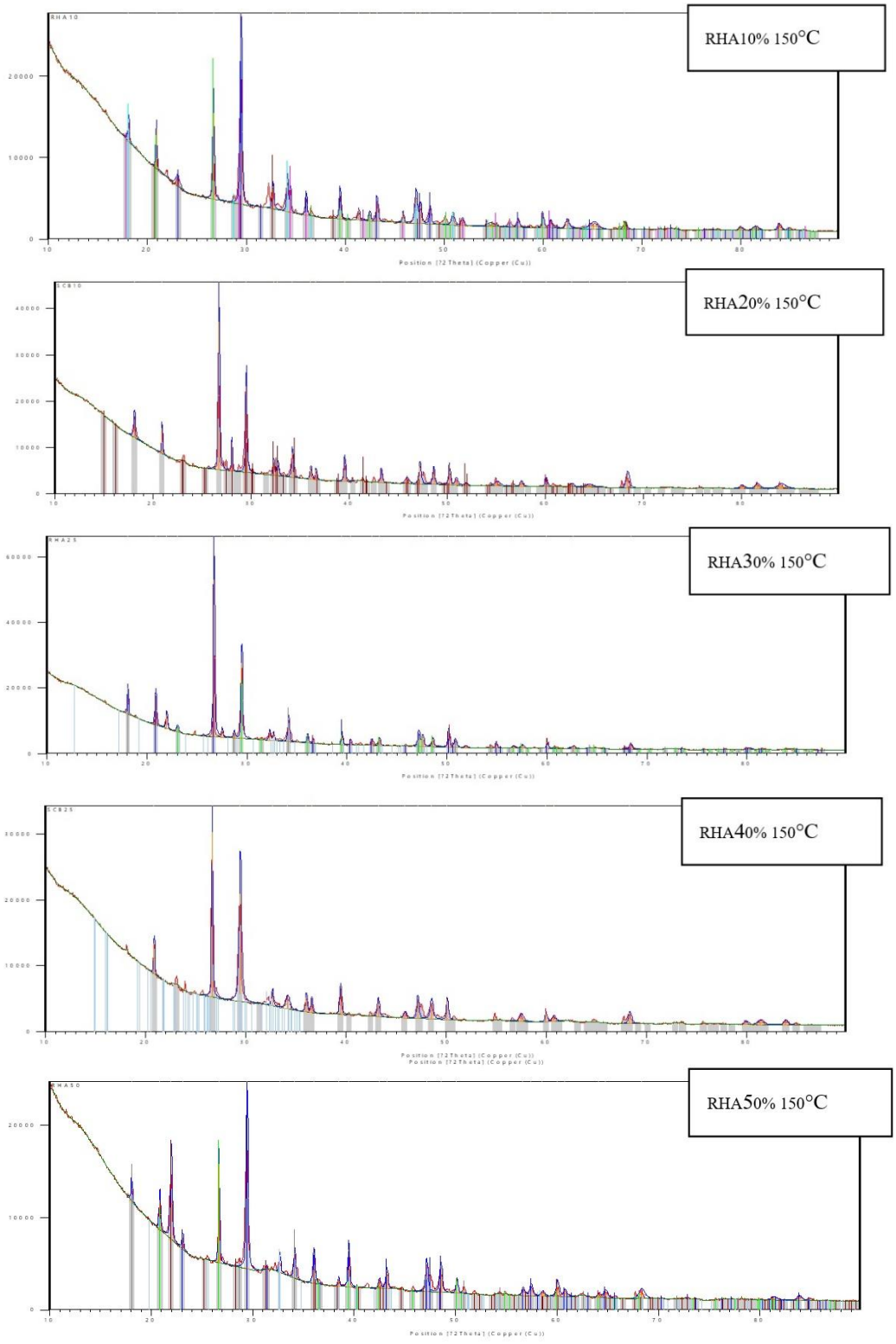


Figure 8. X-ray Diffraction (XRD) analysis of LAC specimens for the different RHA ratios cured for 1 day at 150°C.

X-ray Diffraction testing results are presented in Figure 8 for the different RHA ratios cured for 1 day at 150°C. The diffraction peaks, corresponding to various aggregate components, were analyzed to determine the nature of the chemical reactions and to correlate the findings with other influencing factors. The XRD spectra revealed broadened peaks, indicating the presence of amorphous phases, alongside sharp

peaks that confirmed the formation of crystalline compounds. These results suggest the occurrence of pozzolanic reactions and the development of geopolymer gel throughout the LAC matrix. Representative compounds identified include Calcium Carbonate ($CaCO_3$), Silicon Oxide (SiO_2), Calcium Hydroxide ($Ca(OH)_2$), and Potassium Oxide (K_2O), as summarized in Table 4. The compounds identified through Energy-Dispersive X-ray Spectroscopy (EDX) analysis possess properties that contribute significantly to the mechanical performance of concrete. These elements play a crucial role in enhancing the bonding within the concrete matrix and offer additional mechanical benefits. Our findings are consistent with the conclusions reported in previous studies [24, 25].

Table 4. Summary of elements identified from EDX analysis

Score	Compound Name	Scale Factor	Chemical Formula
71	Calcium Carbonate	0.875	Ca (CO_3)
62	Silicon Oxide	0.536	SiO_2
51	Calcium Hydroxide	0.216	Ca $(OH)_2$
38	Silicon Oxide	0.434	Si O_2

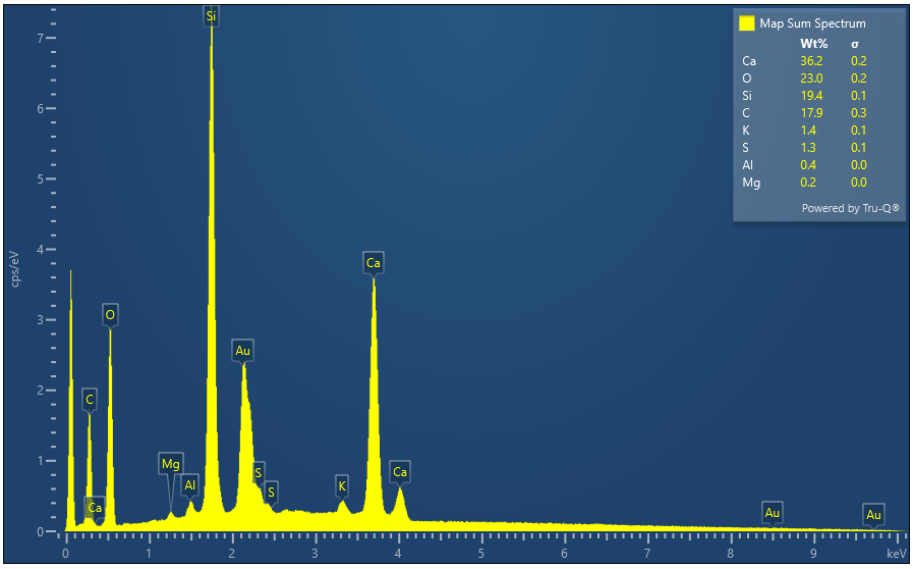


Figure 9. Elemental composition identified by EDX analysis

As shown in Figure 9, the elemental analysis of the 50% RHA specimen (the highest replacement ratio), cured for 1 day (the shortest curing time) at 150°C (the lowest energy input), analyzed using Energy-Dispersive X-ray Spectroscopy (EDX), revealed a high concentration of Silicon (Si), Calcium (Ca), Carbon (C), and Aluminum (Al). Among these, Al and Si are key elements involved in the formation of polymer chains within the geopolymer matrix, in accord with findings reported in Chindaprasirt et al. [26].

4.3 Thermal Conductivity

The thermal conductivity of LAC specimens was measured using a heat flow meter apparatus, with two specimens tested in accordance with ASTM C2 -5 1 8 1. The analysis focused on samples for all RHA replacement ratios cured at 150°C and two curing durations: 1 day and 28 days. The results are shown in Figure 1 0 . It was observed that the higher the RHA ratio and the longer the curing time, the lower the thermal conductivity. These results fall within the range of values observed by Noman et al. [9] for lightweight aggregate bricks by replacing ground blast furnace slag with 15% RHA of 0.978 W/m·K.

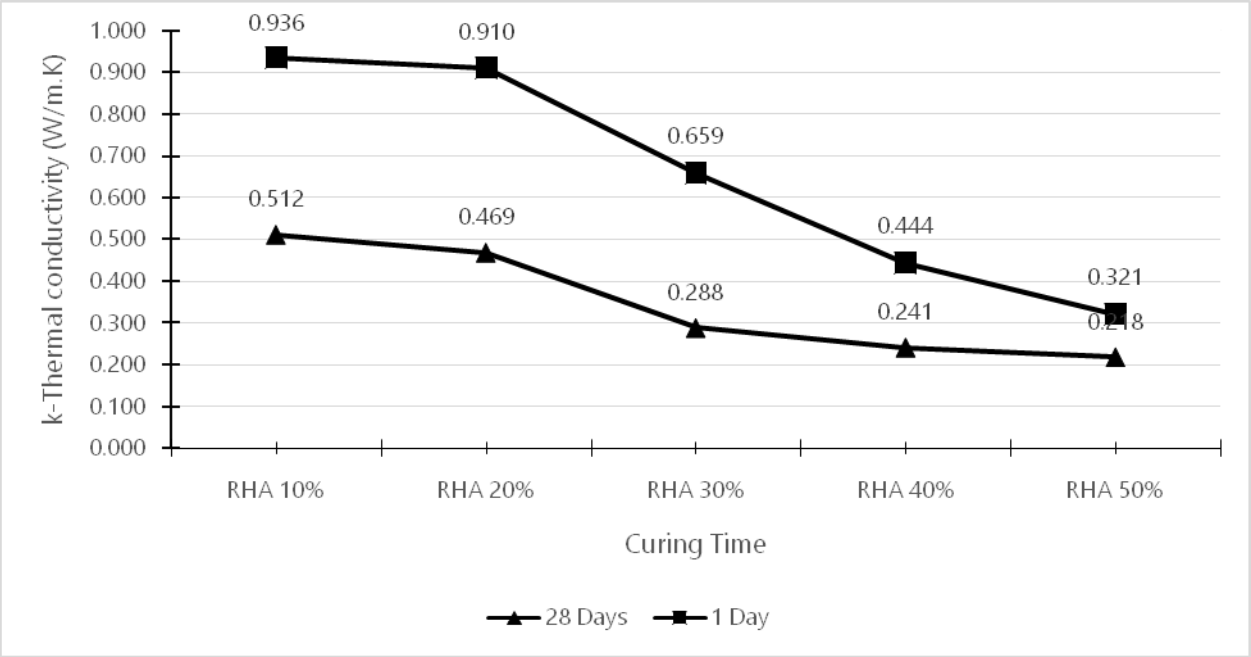


Figure 10. Measured thermal conductivity at 150°C curing temperature for 1 and 28 curing days

4. Conclusions

This paper demonstrates that production of non-load-bearing Lightweight Aggregate Concrete (LAC) with sand partially replaced by rice husk ash (RHA) using a simple thermal curing process was a viable option. This method simplifies the production process, eliminating the need for expensive machinery and complex procedures, while significantly reducing curing time. All specimens with different sand replacement ratios, curing temperatures (150 and 180°C), and times of 1 and 28 days met all requirements of non-load-bearing concrete blocks. The highest strength of 16.95 MPa was observed in the mix containing 30% RHA, cured at 180°C for 28 days. In terms of curing temperature, no significant differences were observed between 150°C and 180°C. Therefore, using the lower temperature of 150°C is recommended to reduce energy consumption while still achieving stable product formation and satisfactory mechanical performance. Similarly, 1-day curing produced specimens that met the standard, suggesting that shorter curing times may be viable for production, enabling faster delivery of LAC products without compromising quality. Due to the incorporation of RHA, the thermal conductivity was low, with a minimum of 0.218 W/m·K for 50% RHA, confirming the material's suitability for use in nonloadbearing wall insulation applications. Finally, the proposed method and 50% RHA offer significant advantages in reducing production costs and helping preserve natural sand resources. The primary objective of the present study was to investigate the effects of rice husk ash replacement ratio and curing temperature on the physical, mechanical, thermal, and microstructural properties of the developed composite. Therefore, durability-related properties, including water absorption, porosity, and resistance to wet–dry cycles, were beyond the scope of the current investigation. Future work will focus on comprehensive durability evaluation, including water absorption, total porosity, permeability, wet–dry cycling, and other long-term durability assessments, to further validate the suitability of the material for practical construction applications. This approach enables communities and small-scale industries to produce LAC, supporting sustainable construction practices and local economic development.

5. Acknowledgments

Author Contributions: Songwit Srijunruk: Method, Conceptu alization, Investigation, visualization, analysis, writing original draft, review & editing. Dusit Ngamrungroj: conceptualuzation, Investigation, analysis,

writing original draft, review & editing. Joseph Khedari: Investigation, analysis, review & editing. Preeda Chantawong: Conceptualization, Method, Investigation, analysis, writing original draft, review & editing.

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