Jurnal Penelitian Fisika dan Aplikasinya (JPFA)
Volume 15, Issue 2, 13-33 2025
https://journal.unesa.ac.id/index.php/jpfa/
p-ISSN: 2087-9946
e-ISSN: 2477-1775

Porous Ceramics: The Role of Coffee Grounds and Rice Husk Ash in Physical and Mechanical Properties

Fauzi [1,a,*], Evi Yufita [1,b], Afwandy Taga S [1,c], Rinaldi Romar [1,d], Musvira [1,e], Dini Rizqi Dwi Kunti Siregar [1,f], Endi Suhendi [2,g], Elin Yusibani [1,h]

[1] Physics Department Faculty of Mathematics and Natural Sciences Universitas Syiah Kuala
Jl. Teuku Nyak Arief Darussalam Banda Aceh 43111 Indonesia
[2] Physics Study Program, Universitas Pendidikan Indonesia, Jl. Setiabudi Bandung, 40154, Indonesia

e-mail: [a] fauzi@usk.ac.id; [b] eviyufita@usk.ac.id; [c] afwandy3@gmail.com; [d] reinamasaya898@gmail.com; [e] amusvira@gmail.com; [f] dinirizqidwi@usk.ac.id; [g] endis@upi.edu; and [h] e_yusibani@usk.ac.id
* Corresponding Author

Received: 26 June 2025; Revised: 11 August 2025; Accepted: 30 December 2025

Abstract

This research investigates the role of spent coffee grounds (SCGs) and rice husk ash (RHA) as additives in clay mixtures for the production of porous ceramics. Three sample variations were tested. The first involved mixing SCGs with clay in weight percentages of 0:100, 5:95, 10:90, 15:85 and 20:80 wt.%, using particles sized between 80 and 100 mesh. In the second variation, SCGs were replaced with RHA in similar proportions. The third variation used a fixed 10 wt.% SCG content, combined with varying RHA percentages (0, 5, 10, 15 and 20) wt.%. Physical properties (density, porosity, water absorption) and mechanical properties (compressive strength) were evaluated. The results show that increasing the proportion of organic filler significantly decreases both density and compressive strength—by up to 45% and 97%, respectively—due to the reduced clay content. Conversely, porosity and water content increase with higher filler content. Among all samples, the clay–RHA mixture exhibited the highest compressive strength. Meanwhile, ceramics containing a mixture of 10 wt.% SCGs with 20 wt.% RHA exhibited the lowest density and indicating the most porous structure.

Keywords: *Ceramic; Porous; Density; RHA; SCGs*

How to cite: Fauzi, Yufita, E., Afwandy Taga-S, A, Romar, R., Musvira, Siregar, D.R.D.K, Suhendi, E., Yusibani, E. Porous Ceramics: The Role of Coffee Grounds and Rice Husk Ash in Physical and Mechanical Properties. *Jurnal Penelitian Fisika dan Aplikasinya (JPFA)*. 2025; 15(2): 13-33. DOI: https://doi.org/10.26740/jpfa.v15n2.p13-33.

INTRODUCTION

Indonesia's vast agricultural land makes the sector a key pillar of national economic development. Major agricultural products such as coffee and rice play a significant role in this growth. However, their production also generates considerable waste, including spent coffee grounds (SCGs) and rice husks ash (RHA), which are often treated as low-value or disposable materials. With increasing awareness of circular economy principles and the need for environmentally sustainable practices, these agricultural byproducts are now being explored for their potential to reduce environmental impact and create added value. Coffee is one of Indonesia's key plantation commodities, playing a significant role in the national economy. During coffee processing, by-products such as coffee skin, pulp, and SCGs account for approximately 45% of the total weight of the coffee fruit [1]. Both small-scale and industrial coffee processing generate SCGs as waste [2,3]. Unfortunately, SCGs are often discarded directly into landfills, posing potential environmental risks. Over time, certain compounds in coffee grounds can be toxic to aquatic organisms, contributing to long-term ecological harm. The properties of SCGs are influenced by various factors, including the grinding method [4,5], brewing technique [6–8], water temperature [9], and post-brewing treatment. Studies have shown that SCGs contain several bioactive compounds such as caffeine, antioxidants [10–13], and phenolic compounds [14–16]. Elemental analysis of SCGs has identified the presence of carbon, hydrogen, oxygen, nitrogen, potassium, phosphorus, manganese, magnesium, calcium, sodium, and iron [17–19]. Numerous studies have explored the potential reuse of SCGs in a range of applications, including composting, fertilizers, oil extraction, and biodiesel production [20–22]. SCGs have also been used as a direct energy source and as raw material for biomass pellets [23,24]. Due to their porous structure and excellent adsorption properties. SCGs have found applications in the production of activated carbon, adsorbents for metal ion removal, coloring agents, and lightweight ceramic aggregates [25–28]. Additionally, research by Ref. [29] investigated how variations in residue composition in dimensional stone affect the properties of porous ceramic tiles, finding that apparent porosity ranged from approximately 21–25% in silicate samples and up to 30% in carbonate-based samples. Similarly, variations in SCGs content in this study influence the physical and mechanical properties of the resulting porous ceramics.

Rice husks ash is a by-product of rice milling and are abundantly available in Indonesia, one of the world's largest rice producers. Approximately 20–30% of the total weight of harvested rice grain is converted into husks during the milling process. According to data from the Central Statistics Agency (BPS) in 2023. Indonesia's annual rice production in recent years has reached around 54–56 million tons of dry grain, resulting in an estimated 12–13 million tons of rice husks. These estimates are based on the assumption that 20–22% of dry grain becomes husk during processing. Despite their abundance, rice husk is often underutilized and frequently discarded. Due to their hard, lignocellulosic surface, they decompose very slowly, making them resistant to microbial breakdown. As a result, open burning is commonly used to reduce waste volume. However, this practice generates smoke and produces RHA, contributing to air pollution. Rice husks, however, hold considerable potential for value-added applications. They can be used as alternative fuels, raw materials in construction (e.g., particle boards), and precursors for biomaterials such as silica and activated carbon. As a form of lignocellulosic biomass, rice husks are rich in silica and typically comprise around 50% cellulose, 25–30% lignin, and 15–20% silica. When burned, they yield ash equivalent to 17–20% of the original weight. with a bulk density ranging from 180 to 200 kg/m^3 [30]. Clay is an abundant natural resource composed primarily of fine-grained minerals, typically originating from secondary geological processes. It consists mainly of alumino-silicate structures, with additional elements such as iron, alkalis, and alkaline earth metals [31]. Due to its plasticity, clay is easily shaped. and when fired at temperatures below 1000°C, it undergoes vitrification—a process that enhances its strength and durability [32]. Clay is widely used as a raw material in ceramic production. As a sustainable alternative, incorporating organic waste materials such as spent coffee grounds and rice husk ash into clay mixtures is increasingly being explored. The chemical compositions of clay, RHA, and SCGs are tabulated in Table 1.

Table 1. Chemical composition of ceramic raw materials: clay, SCGs, and RHA.

Content	Clay (%) [28]	RHA (%) [33]	SCGs (%) [28, 34]
Inorganic			
Silica (SiO_2)	52.77	89.9 – 97.9	0.37
Fe_2O_3+FeO	7.89		0.02
Iron oxide (Fe_2O_3)		0.00 – 0.54	
Alumina (Al_2O_3)	17.95		0.03
Calcium oxide (CaO)	2.57	0.20 – 1.50	0.19
Magnesium oxide (MgO)	3.88	0.12 – 1.96	0.17
Potassium oxide (K_2O)	2.85	0.58 – 2.50	0.58
Sodium oxide (Na_2O)	0.66	0.00 – 1.75	0.14
TiO_2			0.01
P_2O_5		0.20 – 2.84	
Sulfur trioxide (SO_3)		0.10 – 1.13	
Cl_2		0.00 – 0.41	

Previous research on the use of organic materials as ceramic fillers has shown that increasing the proportion of coffee grounds in clay mixtures leads to a reduction in density and compressive strength. while porosity and water absorption tend to increase [35,36]. These findings highlight the potential of organic waste to influence the physical and mechanical properties of ceramics. Incorporating spent coffee grounds and rice husk ash into clay offers a sustainable approach to managing agricultural waste while addressing environmental challenges. This strategy supports the development of innovative materials for energy and construction applications. By converting agricultural by-products into value-added materials, it fosters economic opportunities and contributes to the advancement of a circular economy. With adequate research and technological innovation, these materials can be developed into commercially viable products, enhancing both environmental sustainability and economic resilience. Furthermore, such initiatives can play a role in improving the livelihoods of agricultural communities in Indonesia. This study aims to investigate the effects of local organic waste—specifically spent coffee grounds and rice husk ash—on the characteristics of porous, clay-based ceramics.

METHOD

The primary raw materials used in this study were clay, spent coffee grounds (SCGs), and rice husk ash (RHA). The clay used in Sample I was collected from a riverside area in the Gayo Highlands (GPS: 4.0259858, 97.2851734), while the SCGs were obtained from a local coffee shop in Takengon (GPS: 4.6250010, 96.8458058). The clay used in Samples II and III was collected from brick craftsmen in Blang Bintang, Aceh Besar (GPS: 5.527079, 95.404590). In addition, the SCGs for Sample III were collected from a local coffee shop in Banda Aceh, and the RHA in samples II and III was obtained from the Meutuah Baro Rice Mill, Aceh Besar (GPS: 5.526191, 95.403840). Each physical property test was conducted on three specimens' samples to ensure data reproducibility and reliability. The preparation process began by cleaning the SCGs to remove any impurities, followed by sun-drying. The dried SCGs were then heated at 110°C to eliminate residual moisture and subsequently cooled to room temperature. All raw materials were ground into fine powder using a crusher and then sieved to obtain a uniform particle size between 80 mesh (0.177 mm) and 100 mesh (0.149 mm). Three sample groups were prepared: (sample I) Clay mixed with SCGs at weight percentages of 5, 10, 15, and 20 wt.%, (sample II) Clay mixed with RHA at the same weight percentages (sample III) Clay mixed with 10 wt.% SCGs combined with varying RHA percentages (0, 5, 10, 15, and 20 wt.%). After the mixing process was completed, the sample was placed into a 15 × 15 cm mold lined with aluminum foil and then compressed using a hydraulic press machine at pressure of 2,62 MPa. After pressing, the sample was removed from the mold and cut into specimens measuring 2.5 × 4.5 cm. After sample preparation, the vitrification and sintering processes were conducted under the following conditions: Sample I underwent vitrification at 110 °C for 2 h followed by sintering at 1000 °C for 2 h. Sample II was vitrified at 400 °C for 2 h and subsequently sintered at 900 °C for 5 h. Sample III underwent vitrification at 450 °C for 2 h followed by sintering at 900 °C for 6 h. All heating processes were performed at a controlled heating rate of 5 °C/min. The sample preparation process is illustrated in Figure 1.

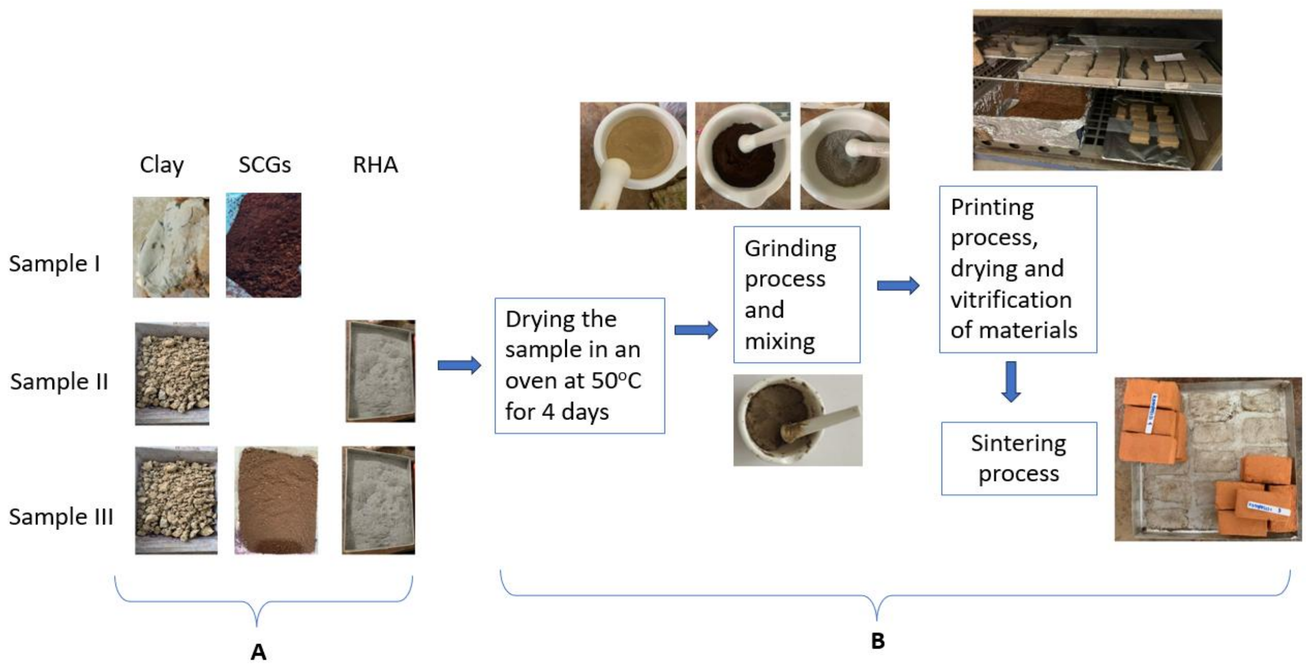


Figure 1. (A) Variations in the mixture of ceramic samples made from clay, SCGs, and RHA (B) process of making ceramic samples.

Following sintering, the ceramic samples were characterized to evaluate their physical and mechanical properties, including density, water absorption, porosity, and compressive strength using a Universal Testing Machine (HUNG TA®). The dimensions of the test specimens were (4 × 2 × 1) cm, in accordance with SNI-03-4164-1996. Density was calculated using Eqs. (1), where ρ is density (g/cm^3), m is sample mass (g), and V is sample volume (cm^3).

$$\rho = \frac{m}{V} \tag{1}$$

Porosity was determined using Eqs. (2), where W_s is saturated weight (kg), W_d is dry weight (g), and W_i is immersed weight.

$$Porosity\ (\%) = \frac{W_s - W_d}{W_s - W_i} \times 100 \tag{2}$$

Water absorption was determined using Eqs. (3), where W_w is wet weight (g) and W_d is dry weight (g).

$$Water\ absorption\ (\%) = \frac{W_w - W_d}{W_d} \times 100 \quad (3)$$

Compressive strength was calculated using Eqs. (4), where σ is compressive strength (MPa), F is maximum load (N), and A is cross-sectional area (m^2).

$$\sigma = \frac{F}{A} \quad (4)$$

RESULTS AND DISCUSSION

Density

Figure 2(a) presents the density of the ceramic samples in comparison with those reported by other researchers. The RHA mixture resulted in relatively higher density, suggesting that RHA contributes to a denser structure than SCGs. The lowest density was 0.9 g/cm^3 in ceramics containing 20 wt.% SCGs (sample I) and 20 wt.% RHA+10 wt.% SCGs (sample III). When SCGs is added to clay, the SCGs particles fill the spaces between clay particles but reduce the overall packing efficiency, leading to lower density. During the sintering process, the organic nature of SCGs causes it to decompose and release gases, forming pores within the ceramic. These pores significantly contribute to the reduction in density [35]. SCGs decomposition refers to the breakdown of its organic components into simpler substances.

A similar trend was observed in ceramics containing RHA: the density values decreased as the RHA content increased, indicating that RHA also introduces porosity into the ceramic matrix, albeit to a lesser extent than SCG. The lowest density observed for a sample containing 20 wt.% RHA+10 wt.% SCGs was 0.9 g/cm^3. Among all RHA compositions, the 10 wt.% RHA mixture showed the highest density at 1.45 g/cm^3, indicating it is the optimal composition. This result aligns with findings from previous research [31]. A 10% RHA composition provides a favorable balance between organic content and mineral components in the mixture. The presence of organic materials, when combined with minerals, increases porosity and reduces the material's overall density. When RHA is mixed with clay, the RHA particles occupy spaces between the clay particles, which can reduce packing efficiency and, consequently, the sample's density. During the sintering process, rice husk —being rich in organic substances such as carbon, cellulose, and lignin—undergoes thermal decomposition, releasing gases that form additional pores in the ceramic body and remain in silica after burning (RHA). These pores contribute significantly to the decrease in density.

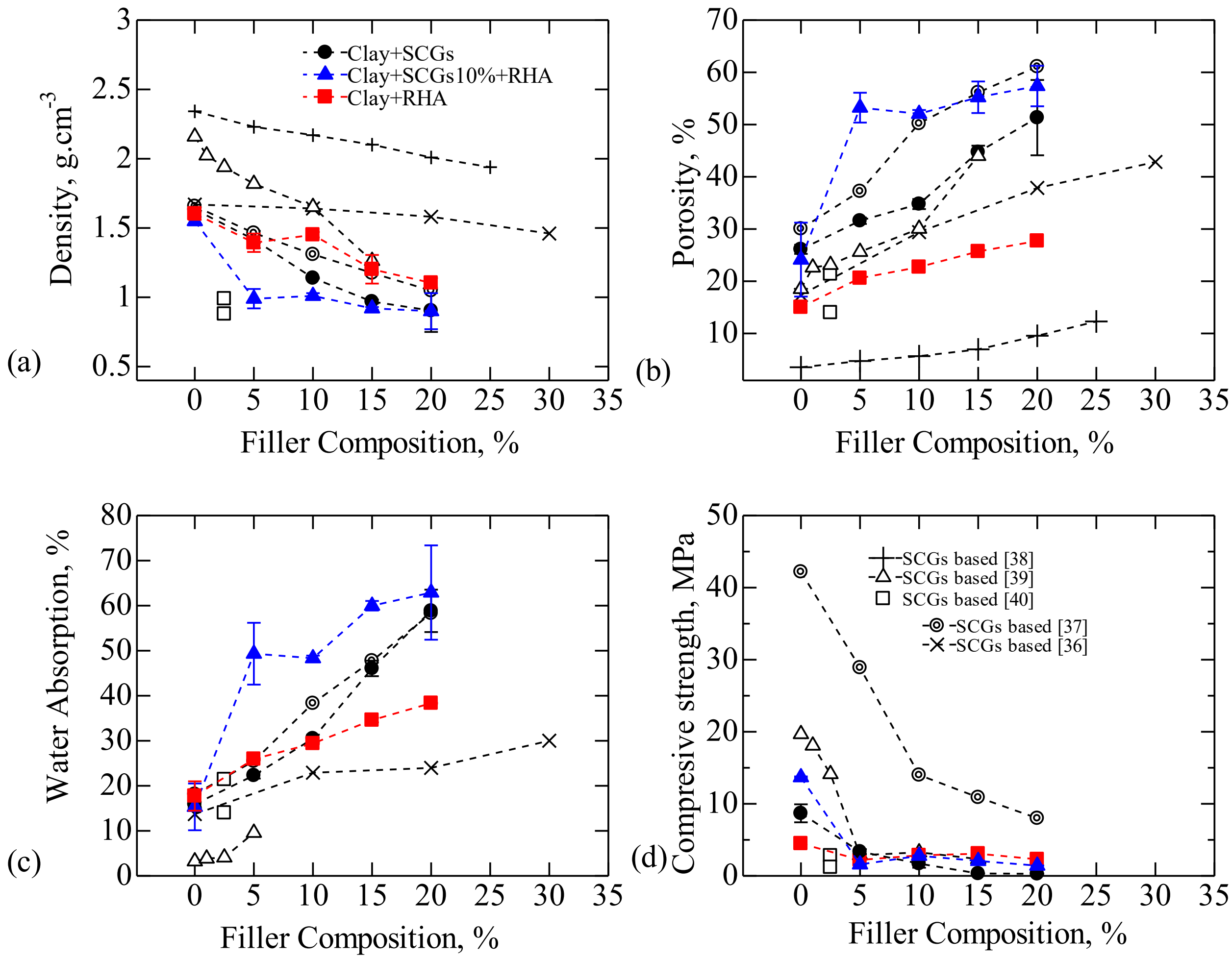


Figure 2. The measurements result of (a) density, (b) porosity, (c) water absorption, and (d) compressive strength compared with those reported by other researchers

Porosity

Porosity refers to the ratio of pore volume to the total volume of a material and is typically expressed as a percentage. In this study, porosity was determined by immersing the ceramic samples in water for 24 h to measure the volume of water absorbed into the pores. The porosity results for clay-based ceramics, based on varying compositions of SCGs and RHA, are shown in Figure 2(b). The figure indicates an overall increasing trend in porosity with different slopes, depending on the type and amount of organic filler used. As the proportion of SCGs, RHA, or their combination increases in the mixture, the porosity also tends to increase. This trend is closely related to the decrease in density, which occurs as more pores form within the ceramic structure. Ceramic samples containing RHA generally exhibited lower porosity (ranging from 20.6% to 27.72%) compared to those containing SCGs. The higher porosity observed in SCGs-containing samples is consistent with their greater organic content, which leads to more pore formation during sintering. These findings are in line with the results reported by Ref. [33]. The highest porosity values were observed in samples containing both SCGs and RHA, reaching as high as 53.24% to 57.38%. This can be attributed to the lower density of SCGs and RHA compared to clay. When these materials are mixed with clay, they disrupt the compact structure and generate more pores, significantly increasing overall porosity.

Water absorption

The water absorption of ceramic samples increased with the addition of SCGs, RHA, and their combination, as shown in Figure 2(c). The porosity of each material significantly influences the water absorption capacity of the ceramics—higher porosity means more void spaces are available for water to occupy. This study found the highest water absorption in samples containing the SCGs + RHA combination, which correlates with their density and porosity characteristics. These samples exhibited the highest water absorption rates, ranging from 49.35 to 62.91%, alongside the lowest densities of 0.90 to 0.99 g/cm^3. Ceramics mixed solely with RHA showed lower water absorption values compared to those with SCGs, as RHA has a higher density, resulting in fewer pores and less water uptake.

Compressive strength

Compressive strength is defined as the maximum compressive stress that a material can withstand before failure under an applied compressive load. It represents the ability of a material to resist deformation, cracking, or fracture when subjected to compression. The control sample (100% clay) exhibited a different compressive strength behavior compared to the others. The highest compressive strength was observed in sample III, reaching 13 MPa. This result is mainly influenced by the sampling location, vitrification and sintering holding time, and particle size distribution. Sample III had a particle size of < 0.177 mm (<80 mesh), indicating the presence of finer particles within the sample. In addition, the longer sintering time (by 1 h), higher temperature (by 100°C), and vitrification process may have further enhanced the strength. Furthermore, the clay used in sample III was predominantly red clay, which also contributed to the improved compressive strength. The effect of varying proportions of SCGs and RHA in clay-based ceramics on compressive strength is illustrated in Figure 2(d). The figure shows that the highest compressive strength occurs in samples containing 15%RHA in sample II, while the lowest is observed in those with 20%SCGs in sample I. The high compressive strength value was attributed to the different clay composition compared to the other samples. However, increasing the filler leads to a decline in compressive strength. This reduction occurs because excessive filler (RHA/SDGs) disrupts the clay matrix, decreasing overall density and weakening the bonding between clay particles and filler. Thus, a 10% RHA composition provides an optimal balance for compressive strength, consistent with findings reported by other researchers [31]. Ceramic samples mixed with SCGs exhibited compressive strength values ranging from 0.29 to 3.36 MPa. As the proportion of SCGs increases and clay content decreases, the compressive strength of the ceramic's declines. Table 2 presents the density, porosity, water absorption, and compressive strength values for each ceramic sample with varying SCGs and RHA compositions. Comparative research parameters are summarized in Table 3. According to Ref. [33], the highest compressive strength reported was 47.1 MPa, whereas the lowest value, 9 MPa, was obtained for ceramics with a 20:80 SCGs-to-clay weight ratio. These results indicate that reducing clay content significantly decreases the mechanical strength of ceramics.

Table 2. Measurement result of the present data

Sample type	Filler composition (wt.%)	Density (g/cm^3)	Porosity (%)	Water absorption (%)	Compression strength (MPa)
I Clay+SCG	SCG				
	0	1.63 ±0.015	26.11 ±0.87	15.92 ±0.53	8.68±1.25
	5	1.42 ±0.062	31.58 ±0.61	22.30 ±0.69	3.36±0.34
	10	1.14 ±0.004	34.78 ±0.96	30.50 ±0.85	1.70±0.57
	15	0.97 ±0.014	44.72 ±1.24	46.06 ±1.72	0.33±0.01
	20	0.90 ±0.154	51.33 ±7.21	58.84 ±4.71	0.29±0.05
II Clay+RHA	RHA				
	0	1.60±0.045	15.02±2.39	17.74±3.27	4.49
	5	1.39±0.066	20.60±0.11	25.94±0.18	2.22
	10	1.45±0.02	22.72±0.09	29.40±0.15	2.85
	15	1.20±0.103	25.70±0.28	34.59±0.51	3.09
	20	1.10±0.034	27.72±0.06	38.35±0.18	2.30
III Clay+ RHA+10 wt.% SCG	RHA+10 wt.%SCG				
	0	1.55±0.03	24.14±7.08	15.32±5.19	13.69±0.11
	5	0.99±0.07	53.24±2.86	49.35±6.85	1.59±0.01
	10	1.01±0.02	52.05±0.74	48.32±0.60	2.79±0.05
	15	0.92±0.01	55.23±3.02	59.97±1.06	2.07±0.04
	20	0.90±0.13	57.38±3.88	62.91±10.47	1.42±0.01

Table 3. Comparison to the other researchers

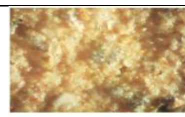
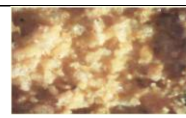
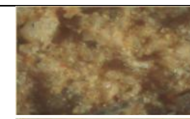
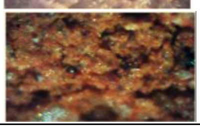
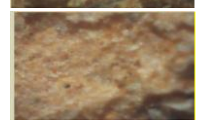
References	[38]	[39]	[40]	[36]	[37]	This study
SCGs mixture						
Sintering Temperature (°C)	1220	50 for 48h and 110 for 24h (gunfire sample/curing process)	1000 for 1-2 min	1150 for 2.5 h	900, 1000, 1100	SI:1000 for 2 h SIII:900 for 6 h
Particle size (mm)	SCG:~0.074 40 wt.% plastic red clay, 47.5 wt.% Na-feldspar, and 12.5 wt.% quartz: <0.045	SCG: 1.30 (median) Tea waste: 0.31 (median) Clay: 0.02 (median)	Clay: 0.2	SCG: 0.063 clay: 0.01	SCG: 0.5 – 0.125 Clay: 0.05 – 0.1	S1: 0.149 (mesh 100)-0.177 mm (mesh 80) SIII <0.177 mm (<mesh 80)
product	dense/porous bi-layered floor tiles	Alkali-Activated Bricks	lightweight aggregates	ceramic	ceramic	Porous ceramic
Referensi	[31]	[41]	[42]			
RHA mixture						
Sintering Temperature (°C)	950 for 2 h	600 for 2 h	1000 for 4 h			SII:900 for 5 h

Particle size (mm)	nd	RHA: 325 mesh	RHA; 100 µm, wood ash; 100 µm, Clay: 500 µm		SIII <0.177 mm (<mesh 80)
product	Brick	Cement composite	Brick		Porous ceramics

Nd: non determination

Table 4 shows the morphology of sample II (with RHA addition) observed using an optical microscope (Digital Microscope Live Blood Analysis) at 50× magnification to examine the surface structure of the sample after the sintering process. The table indicates that the sintering treatment affected the sample surface, which appeared smoother, indicating the closure of the sample pores.

Tabel 4. Sample morphology with RHA addition

	0 wt.% RHA	5 wt.% RHA	10 wt.% RHA	15 wt.% RHA	20 wt.% RHA
Before sintering					
After sintering					

The relationships among density, porosity, water absorption, and compressive strength indicate that increasing porosity generally reduced the density and compressive strength of the ceramics. SCGs mainly acted as an organic pore-forming agent because the combustion of organic constituents during sintering generated additional pores within the ceramic matrix. In contrast, RHA contributed differently due to its high silica content, which may enhance the ceramic framework and affect the densification behavior. Therefore, the balance between pore formation and matrix strengthening significantly influenced the final physical and mechanical properties of the porous ceramics. The results of this study demonstrate the potential application of SCGs–RHA porous ceramics as environmentally friendly materials for water filtration, lightweight construction materials, and thermal insulation systems. The utilization of agricultural waste in ceramic production also supports sustainable material development and circular economy principles by reducing solid waste and converting biomass residues into value-added products.

CONCLUSION

Based on the research results, the composition of SCGs and RHA in clay-based ceramics significantly influences their physical and mechanical properties. Adding these two materials reduces the clay content in the ceramics. As the proportion of SCGs and RHA increases, the density and compressive strength of the ceramics decrease, while water absorption and porosity increase. Variations in compressive strength are primarily affected by the ratio between SCGs and RHA fillers and the clay matrix. The study found that ceramics with RHA alone exhibited the highest compressive strength compared to those with SCGs or a combination of SCGs and RHA. A density variation between 0.9 and 1.4 g/cm³ was observed, with porosity and water absorption values ranging from 20% to 57% and 22% to 62%, respectively. The corresponding compressive strength ranged from 0.3 to 3.3 MPa. Samples containing the SCGs + RHA mixture had the lowest density, resulting in the most porous structure among all specimen samples. This combination shows promise for applications requiring highly porous ceramics. Overall, this research suggests that SCGs and RHA waste materials can be effectively used as partial replacements for clay in the production of porous ceramics. The addition of SCGs and RHA significantly affected the physical and mechanical properties of porous ceramics. Increasing SCGs content tended to increase porosity and water absorption due to its role as an organic pore-forming agent, whereas RHA contributed silica that influenced the ceramic matrix differently. The balance between densification and pore formation controlled the compressive strength and overall performance of the ceramics.

AUTHOR CONTRIBUTIONS

Fauzi: Writing Original Draft, Methodology, Formal Analysis; Evi Yufita: ensure data reproducibility and reliability, Afwandy Taga S: Data Curation sample I, Rinaldi Romar: Data Curation sample II,, Musvira: Data Curation sample III, Dini Rizqi Dwi Kunti Siregar: Validation experiment data; Endi Suhendi: Review the article; Elin Yusibani: Conceptualization, Methodology, Resources and Validation

DECLARATION OF COMPETING INTEREST

The authors declare no known financial conflicts of interest or personal relationships that could have influenced the work reported in this manuscript.

DECLARATION OF ETHICS

The authors declare that the research and writing of this manuscript adhere to ethical standards of research and publication, in accordance with scientific principles, and are free from plagiarism.

DECLARATION OF ASSISTIVE TECHNOLOGIES IN THE WRITING PROCCESS

The authors affirm that Generative Artificial Intelligence and other assistive technologies were not excessively utilized in the research and writing processes of this manuscript.

REFERENCES

[1] Esquivel P and Jiménez VM. Functional Properties of Coffee and Coffee By-Products. Food Res Int. 2012; 46: 488-495. DOI: http://dx.doi.org/10.1016/j.foodres.2011.05.028.

[2] Cordoba N, Fernandez-Alduenda M, Moreno FL, Ruiz Y. Coffee extraction: a review of parameters and their influence on the physicochemical characteristics and flavor of coffee brews. Trends Food Sci Technol. 2020; 96: 45-60. DOI: http://dx.doi.org/10.1016/j.tifs.2019.12.004.

[3] Simões J, Nunes FM, Domingues MR, Coimbra MA. Extractability and structure of spent coffee ground polysaccharides by roasting pre-treatments. Carbohydrate Polymers. 2013; 97(1): 81-89. DOI: http://dx.doi.org/10.1016/j.carbpol.2013.04.067.

[4] Andueza S, de Peña MP, Cid C. Chemical and sensorial characteristics of espresso coffee as affected by grinding and torrefacto roast. Journal of Agricultural and Food Chemistry. 2003; 51(24): 7034-7039. DOI: http://dx.doi.org/10.1021/jf034628f.

[5] Cordoba N, Pataquiva L, Osorio C, Moreno FLM, Ruiz RY. Effect of grinding, extraction time and type of coffee on the physicochemical and flavor characteristics of cold brew coffee. Scientific Reports. 2019; 9(1): 8440. DOI: http://dx.doi.org/10.1038/s41598-019-44886-w.

[6] De Figueiredo Tavares MP and Mourad AL. Coffee beverage preparation by different methods from an environmental perspective. International Journal of Life Cycle Assessment. 2020; 25(40). DOI: http://dx.doi.org/10.1007/s11367-019-01719-2.

[7] Parenti A, Guerrini L, Masella P, Spinelli S, Calamai L, Spugnoli P. Comparison of espresso coffee brewing techniques. Journal of Food Engineering. 2014; 121: 112-117. DOI: http://dx.doi.org/10.1016/j.jfoodeng.2013.08.031.

[8] Wolska J, Janda K, Jakubczyk K, Szymkowiak M, Chlubek D, Gutowska I. Levels of antioxidant activity and fluoride content in coffee infusions of arabica, robusta and green coffee beans according to their brewing methods. Biological Trace Element Research. 2017; 179(2): 327-333. DOI: http://dx.doi.org/10.1007/s12011-017-0963-9.

[9] Navarini L and Rivetti D. Water quality for Espresso coffee. Food Chemistry. 2010; 122(2): 424-428. DOI: http://dx.doi.org/10.1016/j.foodchem.2009.04.019.

[10] Campos-Vega R, Loarca-Piña G, Vergara-Castañeda HA, Oomah BD. Spent coffee grounds: a review on current research and future prospects. Trends in Food Science & Technology. 2015; 45(1): 24-36. DOI: http://dx.doi.org/10.1016/j.tifs.2015.04.012.

[11] Ramalakshmi K, Rao LJM, Takano-Ishikawa Y, Goto M. Bioactivities of low-grade green coffee and spent coffee in different in vitro model systems. Food Chemistry. 2009; 115(1): 79-85. DOI: http://dx.doi.org/10.1016/j.foodchem.2008.11.063.

[12] López-Barrera DM, Vázquez-Sánchez K, Loarca-Piña MGF, Campos-Vega R. Spent coffee grounds, an innovative source of colonic fermentable compounds, inhibit inflammatory mediators in vitro. Food Chemistry. 2016; 212: 282-290. DOI: http://dx.doi.org/10.1016/j.foodchem.2016.05.175.

[13] Sikka SS, Bakshi MPS, Ichhponani JS. Evaluation in vitro of spent coffee grounds as a livestock feed. Agricultural Wastes. 1985; 13(4): 315-317. DOI: http://dx.doi.org/10.1016/0141-4607(85)90057-5.

[14] Panusa A and Zuorro A. Recovery of natural antioxidants from spent coffee grounds. Journal of Agricultural and Food Chemistry. 2013; 61(17): 4162-4168. DOI: http://dx.doi.org/10.1021/jf4005719.

[15] Xu H and Wang W. Antioxidative phenolics obtained from spent coffee grounds (Coffea arabica L.) by subcritical water extraction. Industrial Crops and Products. 2015; 76: 946-954. DOI: http://dx.doi.org/10.1016/j.indcrop.2015.07.054.

[16] Acevedo F and Rubilar M. Spent coffee grounds as a renewable source of bioactive compounds. Journal of Biobased Materials and Bioenergy. 2013; 7(3): 420-428. DOI: http://dx.doi.org/10.1166/jbmb.2013.1369.

[17] Hejna A and Sulyman M. On the correlation of lignocellulosic filler composition with the performance properties of poly(e-caprolactone) based bio composites. Waste and Biomass Valorization. 2020; 11: 1467-1479. DOI: http://dx.doi.org/10.1007/s12649-018-0485-5.

[18] Mariotti F and Tomé D. Converting nitrogen into protein—beyond 6.25 and Jones' factors. Critical Reviews in Food Science. 2008; 48(2): 177-184. DOI: http://dx.doi.org/10.1080/10408390701279749.

[19] Cruz MV and Paiva A. Production of polyhydroxyalkanoates from spent coffee grounds oil obtained by supercritical fluid extraction technology. Bioresource Technology. 2014; 157: 360-363. DOI: http://dx.doi.org/10.1016/j.biortech.2014.02.013.

[20] Liu K and Price GW. Evaluation of three composting systems for the management of spent coffee grounds. Bioresource Technology. 2011; 102(17): 7966-7974. DOI: http://dx.doi.org/10.1016/j.biortech.2011.05.073.

[21] Couto RM, Fernandes J, da Silva MDRG, Simões PC. Supercritical fluid extraction of lipids from spent coffee grounds. J Supercrit. Fluids. 2009; 51(2): 159-166. DOI: http://dx.doi.org/10.1016/j.supflu.2009.09.009.

[22] Burton R, Fan X, Austic G. Evaluation of two-step reaction and enzyme catalysis approaches for biodiesel production from spent coffee grounds. Int J Green Energy. 2010; 7(5): 530-536. DOI: http://dx.doi.org/10.1080/15435075.2010.515444.

[23] Kelkar S, Saffron CM, Chai L, Bovee J, Stuecken TR, Garedew M, Li Z, Kriegel RM. Pyrolysis of spent coffee grounds using a screw-conveyor reactor. Fuel Process Technol. 2015; 137: 170–178. DOI: http://dx.doi.org/10.1016/j.fuproc.2015.04.006.

[24] Limousy L, Jeguirim M, Dutournié P, Kraiem N, Lajili M, Said R. Gaseous products and particulate matter emissions of biomass residential boiler fired with spent coffee grounds pellets. Fuel. 2013; 107: 323–329. DOI: http://dx.doi.org/10.1016/j.fuel.2012.10.019.

[25] Kante K, Nieto-Delgado C, Rangel-Mendez JR, Bandosz TJ. Spent coffee based activated carbon: specific surface features and their importance for H2S separation process. J Hazard Mater. 2012; 201–202: 141–147. DOI: http://dx.doi.org/10.1016/j.jhazmat.2011.11.053.

[26] Dávila-Guzmán NE, de Jesús Cerino-Córdova F, Soto-Regalado E, Rangel Mendez JR, Díaz-Flores PE, Garza-Gonzalez MT, Loredo-Medrano JA. Copper biosorption by spent coffee ground: equilibrium, kinetics, and mechanism. Clean–Soil Air Water. 2013; 41(6): 557–564. DOI: http://dx.doi.org/10.1002/clen.201200109.

[27] Jung KW, Choi BH, Hwang MJ, Jeong TU, Ahn KH. Fabrication of granular activated carbons derived from spent coffee grounds by entrapment in calcium alginate beads for adsorption of acid orange 7 and methylene blue. Bioresource Technology. 2016; 219: 185-195. DOI: http://dx.doi.org/10.1016/j.biortech.2016.07.098.

[28] Andreola F, Borghi A, Pedrazzi S, Allesina G, Tartarini P, Lancellotti I, Barbieri L. Spent Coffee Grounds in the Production of Lightweight Clay Ceramic Aggregates in View of Urban and Agricultural Sustainable Development. Materials. 2019; 12: 3581. DOI: http://dx.doi.org/10.3390/ma12213581.

[29] Prado CARLM, Feitosa MA, Neves SP, Taguchi S. The influence of compositional variability of dimension stone residues on the properties of rustic porous ceramic tiles. Cerâmica. 2023; 69: 23-29. DOI: http://dx.doi.org/10.1590/0366-69132023693893382.

[30] Zou Y and Yang T. Rice Husk. In: Cheong LZ, Xu X, editors. Rice Bran and Rice Bran Oil. AOCS Press; 2019. p. 207-246. DOI: http://dx.doi.org/10.1016/B978-0-12-812828-2.00009-3.

[31] Damanhuri AAM, Lubis AMHS, Hariri A, Herawan SG, Roslan MHI, Hussin MSF. Mechanical properties of rice husk ash (RHA) brick as partial replacement of clay. J. Phys.: Conf. Ser. 2020; 1529: 042034. DOI: https://doi.org/10.1088/1742-6596/1529/4/042034..

[32] Oliveira GE and Holanda JN. Use of mix of clay/solid waste from steel works for civil construction materials. Journal of Waste Management. 2004; 22: 358-363. DOI: https://doi.org/10.1016/j.wasman.2003.08.004.

[33] Houston DF. Rice Chemistry and Technology. American Association of Cereal Chemists, Inc., Minnesota. 1972.

[34] Massaya J, Prates Pereira A, Mills Lamptey B, Benjamin J, Chuck C. Conceptualization of a spent coffee grounds biorefinery: A review of existing valorization approaches. Food and Bioproducts Processing. 2019; 118: 149-166. DOI: http://dx.doi.org/10.1016/j.fbp.2019.08.010.

[35] Perta-Crisan S, Ursachi C, Munteanu F-D. Trends in valorization of spent coffee grounds: a review. 2019; 16:31-42. https://www.uav.ro/jour/index.php/stb-cfse/article/view/1501.

[36] Manni A, Haddar EA, Hassani EAEI, Bouari EA, Sadik C. Valorization of coffee waste with Moroccan clay to produce a porous red ceramic (class BIII). Boletín de la Sociedad Española de Cerámica y Vidrio. 2019; 58:211-220. DOI: https://doi.org/10.1016/j.bsecv.2018.11.001.

[37] Fonseca DSB, Vila A, Galhano C, Sima JAR. Reusing coffee waste in manufacture of ceramics for construction. Advances in Applied Ceramics. 2014; 113(3). DOI: https://doi.org/10.1179/1743676113Y.0000000131.

[38] Busch PF and Holanda JNF. Potential use of coffee grounds waste to produce dense/porous bi-layered red floor tiles. Open Ceramics. 2022; 9: 100204. DOI: https://doi.org/10.1016/j.oceram.2021.100204.

[39] Chung LLP, Wong YC, Arulrajah A. The application of spent coffee grounds and tea wastes as additives in alkali-activated bricks. Waste and Biomass Valorization. 2021; 12: 4567–4578. DOI: https://doi.org/10.1007/s12649-021-01453-7.

[40] Ceacero CJC, Maroto JMM, Martínez MG, Rodríguez MU, López AB, García CM, Palomino TC. Effect of the addition of organic wastes (cork powder, nut shell, coffee grounds and paper sludge) in clays to obtain expanded lightweight aggregates. Boletín de la Sociedad Española de Cerámica y Vidrio. 2023; 62(1): 88–105. DOI: https://doi.org/10.1016/j.bsecv.2022.02.007.

[41] Bakri. Komponen Kimia dan Fisik Abu Sekam Padi sebagai SCM untuk Pembuatan Komposit Semen. PERENNIAL. 2009; 5(1): 9–14. DOI: https://doi.org/10.24259/perennial.v5i1.184.

[42] Eliche-Quesada D, Felipe-Sesé MA, López-Pérez JA, Infantes-Molina A. Characterization and evaluation of rice husk ash and wood ash in sustainable clay matrix bricks. Ceramics International. 2017; 43(1) Part A: 463–475. DOI: http://dx.doi.org/10.1016/j.ceramint.2016.09.181.