

Characterization of the Coffee Husk: A Potential Alternative for Sustainable Construction

Haidee Yulady Jaramillo¹, Oscar Vasco-Echeverri², July Andrea Gómez Camperos^{3,*}

¹Department of Civil Engineering, Faculty of Engineering, Universidad Francisco de Paula Santander Ocaña, Research Group on New Technologies, Sustainability, and Innovation (GINSTI), Ocaña, Colombia

²Transmission and Distribution of Energy T&D, Universidad Pontificia Bolivariana, Colombia

³Department of Mechanical Engineering, Faculty of Engineering, Universidad Francisco de Paula Santander Ocaña, Research Group on New Technologies, Sustainability, and Innovation (GINSTI), Ocaña, Colombia

Received February 7, 2023; Revised March 20, 2023; Accepted April 16, 2023

Cite This Paper in the Following Citation Styles

(a): [1] Haidee Yulady Jaramillo, Oscar Vasco-Echeverri, July Andrea Gómez Camperos, "Characterization of the coffee husk: A Potential Alternative for Sustainable Construction," *Civil Engineering and Architecture*, Vol. 11, No. 4, pp. 1902 - 1908, 2023. DOI: 10.13189/cea.2023.110418.

(b): Haidee Yulady Jaramillo, Oscar Vasco-Echeverri, July Andrea Gómez Camperos (2023). *Characterization of the coffee husk: A Potential Alternative for Sustainable Construction*. *Civil Engineering and Architecture*, 11(4), 1902 - 1908. DOI: 10.13189/cea.2023.110418.

Copyright©2023 by authors, all rights reserved. Authors agree that this article remains permanently open access under the terms of the Creative Commons Attribution License 4.0 International License

Abstract Agro-industrial wastes are a potential alternative for sustainable construction because they provide a renewable source, reducing raw materials consumption, emissions, and waste production. In the Colombian coffee sector, a big waste amount of husk is developed in its production, which is obtained from the pulping of coffee, being this husk an excellent source of cellulose and lignin, in a natural way. This experimental research aims to characterize the coffee husk as a potential alternative for sustainable construction in dividing walls. The methodology was developed in three steps, concerns from the obtention of the coffee husk in Ocaña Norte de Santander in Colombia to the physical and chemical characterization properties of this material considering the NTC-2441 Colombian Technical Standard. The results showed that the coffee husk presents a humidity of 13.3% with an average particle size of 611.93 μm . Also, the particle size of the coffee husk is related to the threshing process, where the by-product base coffee waste is obtained. In addition, the visualization of internal micro-cracks, carbon, and oxygen composition was possible with the presence of natural fibers using the Scanning Electron Microscopy technique. Finally, the coffee husk exposes in its chemical composition the presence of carbon and lignin, showing a structure with cracks of excellent resistance without the evidence of the samples fracture, which allows concluding that the coffee husk can be a potential and new alternative for sustainable construction for diving walls and another kind of

applications in non-structural masonry in civil engineering, taking into account that in Colombia this bio-material has been little used in the mixture for obtaining products with good physical and mechanical performance.

Keywords Agro-industrial, Coffee Husk, Sustainable Construction, Innovation, Eco-Bricks

1. Introduction

The population growth and the country's development have generated demand for infrastructure and materials for the construction sector, considering the natural raw materials consumption, energy, and solid waste production generated during this process [1]. The construction industry relies heavily on conventional materials such as cement, sand, and aggregates for large amounts of concrete worldwide. Although negative environmental impacts have shifted towards developing environmentally friendly materials from renewable resources [2], by-products or agro-industrial waste can be an alternative as supplementary material for concrete production [3]. The use of agricultural waste, such as coffee husks, provides a source of renewable material in construction and a non-food source of economic development for agriculture and rural areas in different countries [4].

Coffee is an agricultural product of economic and

commercial importance in the current world because it is cultivated in approximately 80 countries [5]. However, in coffee-producing countries, generated waste and by-products are a source of pollution and environmental problems [6] because their production generates large amounts of waste, mainly during the first stage, where coffee beans are transformed into dry coffee, and the husks are separated [7]. On the other hand, coffee waste applications can preserve natural resources, reduce carbon emissions, and contribute to lower solid waste production in different industrial sectors [8].

In the case of Colombia, this country is the third largest producer of coffee in the world, cultivated on approximately 970 thousand hectares [9], with a production of 13.8% which represents 13.5 million bags of coffee, where each bag has a weight of 60 kg, and Norte de Santander has a production of 25 million bags which is equivalent to one [10]. In this agricultural process, it is estimated that less than 5% is used in making coffee drink; the remaining 95% is waste, contaminating the environment [11]. In the Colombian coffee sector, there is a waste amount in its production, mainly the husk, a by-product obtained from the pulping of coffee [12], being this husk an excellent source of cellulose and lignin, which are natural.

In recent years, scientists have become aware of the potential for the efficient and cost-effective application of plant-derived fibers and the likelihood of producing higher-quality fiber-reinforced polymeric materials for construction projects [13]. In this way, research has been conducted using agricultural residues in the construction sector due to their potential properties compared to conventional synthetic fibers. Due to this, there is research on using cellulose fiber materials as reinforcement for concrete and mortar. The natural fiber materials investigated in the current literature have been banana [14], bamboo [15], rice husk [16], wheat and barley straw [17], coconut, sisal, jute, palm, and linseed [18]. However, coffee husk has been used for soil stabilization in different ways with the main aim of sustainability and without waste technologies [1][19]. For example, Reta and Mahto, 2019 [3] used coffee husk ash (CHA) as a partial replacement for the concrete mixture for industrial applications taking into account some physical and chemical properties. The results exposed that CHA as a replacement material can be used for walls and mild works where the strength that can be appears is low, obtaining similar conclusions with other reported research for concrete [20] or clays [21].

The main objective of this work is to characterize the coffee husk produced in Ocaña, Norte de Santander in Colombia, based on the NTC-2441 Colombian Technical Standard [22]. Also, laboratory tests were developed to determine physical and chemical properties such as the particle size, morphology, chemical composition, and structure of the coffee husk, roast, and milled coffee. Notice that this material has been little reported in the open literature revised for the Colombian coffee husk.

2. Materials and Methods

2.1. Samples of Coffee Husk

Samples of coffee husks were provided by the federation of coffee growers in Ocaña city in Norte Santander, Colombia with an annual production of 25 million kgs, with an average of 1,100 kg per hectare. For the laboratories development 10 kg of husk were collected, and distributed in samples of 2.0 kg to address the respective trials.

The tests concerning the calculation of the average particle of coffee husk by grain size distribution were carried out in the soil laboratories of the Universidad Francisco de Paula Santander Ocaña, and those corresponding to scanning electron microscopy (SEM) in the laboratories of the EAFIT University in the city of Medellín. The coffee husk was dried using a conventional oven available in the Francisco de Paula Santander Ocaña University laboratories, in which the sample was subjected to a temperature of 220°C to eliminate any trace of moisture. Also, for the coffee husk grinding, a mill was used. Likewise, for the particle testing, sieves number #50, #40, #20, #16, and #12 were used as stipulated by the NTC-2441 Colombian technical standard [13]. The Curve Expert software was used to calculate the particle size average.

2.2. Physical and Chemical Characterization

The characterization of the coffee husk was developed in 4 phases described as shown in Figure 1. **Phase 1:** The coffee husk is spread and dried at room temperature to remove as much moisture as possible without drying completely. For the temperature calculation, a conventional thermometer with a unit of measurement in degrees Celsius (°C) was used. **Phase 2:** The average humidity of the coffee husk was calculated by implementing the stove method. For this purpose, a sample of 52 gr of husk previously dried at room temperature was used, and the respective calculations were made. **Phase 3:** The milling of the coffee husk and the characterization of the average particle of the coffee husk were performed using the granulometric method contemplated in NTC-2441 Colombian Technical Standard [22]. Also, the weight of each sieve used (#50, #40, #20, #16, and #12) was determined as is stipulated in 6.1, then select 50 gr of the sample to perform the test, as stipulated in 6.2. Finally, after sieving the sample, for 10 min, the final weight of each sieve is determined together with the weight of the material retained in each mesh. **Phase 4:** The coffee husk's structural characteristics and chemical composition were identified through the electronic scanning microscope (SEM) used in the EAFIT University laboratory, those responsible for preparing the sample and then obtaining the micrographs.



Figure 1. Methodology applied

Table 1. Weight of material retained in each sieve

Sieve No	Sieve weight (gr)	Material weight retained (gr)
50	351	18
40	517	16
20	398	9
16	402	5
12	406	2

Considering the proposed experimental methodology, Table 1 summarizes the main results obtained.

Table 2. Calculation of the average drying temperature of the coffee husk

Day	Temperature 1 (°C)	Temperature 2 (°C)	Temperature 3 (°C)	Average(°C)
1	36.9	36.5	36.7	36.7
2	40.1	39.8	40.3	40.1
3	38.1	38.9	38.5	38.5
4	39.0	40.5	40.0	39.8
5	38.7	39.4	38.3	38.8
Total average			38.8±0.32	

3. Results and Discussions

3.1. Calculation of the Drying Temperature of the Coffee Husk

The coffee husk was exposed to room temperature for 5 h of daily drying cycles. Measurements were made with the thermometer 3 times per day to determine the average temperature at which the husks dried (See Table 2). The average ambient temperature at which the coffee husk was dried was 38.8 °C.

3.2. Calculation of Moisture Content of Coffee Husk

Equation 1 was used to calculate the moisture percentage present in the coffee husk, provided by the federation of coffee growers in the city of Ocaña, Norte de Santander, and Table 3 presents the data for the calculation of the moisture present in the coffee husk.

$$\%W = \frac{P_2 - P_3}{P_3 - P_1} \times 100 \quad (1)$$

Where: P1 is the container weight, P2 is the container weight more than the wet sample weight, and P3 is the container weight more than the dry sample (See Table 3).

Table 3. Data for the calculation of humidity

Data Humidity Coffee husk	Unit	Value
Weight Container	(gr)	35
Weight Container + wet sample (P ₂)	(gr)	52
Weight Container + wet sample (P ₃)	(gr)	50
Weight Dry soil	(gr)	15
Weight of water	(gr)	2.0
Moisture content (%W)	(%)	13.33

Replacing the values from Table 3 in Equation 1 was obtained with a moisture of 13.33% from the following calculation:

$$\%W = \frac{52 - 50}{50 - 35} \times 100 = 13.333\%$$

3.3. Average Particle Size of the Coffee Husk Using NTC 2441

Table 4 shows the final weights of the sieves according to the percentages of scale particles retained in each mesh. The maximum temperature obtained during 5 days was 38.8°C, bearing in mind that it was always taken at the same time and dried naturally with constant exposure to the sun.

Figure 2 shows the dried clean husk process and its temperature measurement. Since humidity affects the drying of the husk is necessary because its humidity alters the humidity of the composite mixture where it can be used since it can generate plasticity and compaction problems. Hence, the importance of this procedure within the characterization and the times and temperatures obtained in this procedure are shown below.

Table 4. Recording of the final weights of each mesh after screening

Sieve No.	Sieve diameter	% Accumulated	Initial sieve Weight (gr)	Final sieve weight (gr)	Weight difference	Accumulated	% Retained
12	1700	4	406	408	2	2	4
16	1180	14	402	407	5	7	10
20	850	32	398	407	9	16	18
40	425	64	517	533	16	32	32
50	300	100	351	369	18	50	36



Figure 2. Samples of coffee husk. a) Drying of the sample by the oven method, b) Weight of dry coffee husk + Weight of container, c) Temperature measurement and d) Coffee husk texture in its natural state

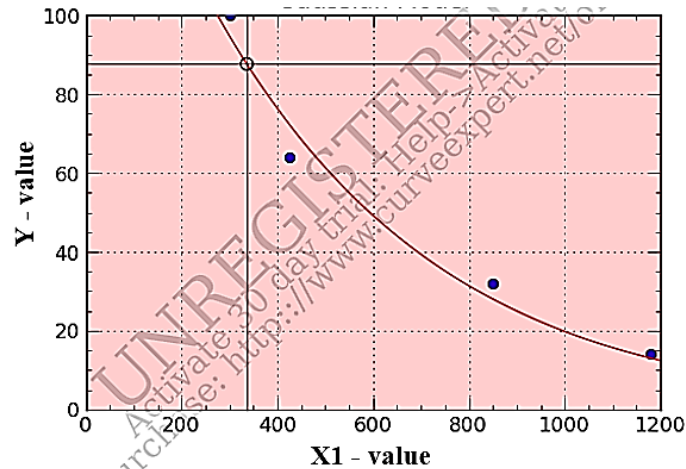


Figure 3. Calculation a, b, and c values using the Gauss method

The average particle size calculation of the coffee husk was obtained, taking into account the Gauss mathematical model using Equation 2. Notice that NTC-2441 [22] was also considered, as was observed in Figure 3.

$$Y = a \times e^{-1/2\left(\frac{X-b}{c}\right)^2} \quad (2)$$

Where: Y is the accumulated percentage calculated by the Gauss Mode, X is the diameter of the sieve, a, b, and c are the parameters of the Gauss model.

With the aim of determining the parameters of a, b, and c values described in the Gauss equation, CurveExpert/Version-1.3 was used. After obtaining the a, b, and c values provided by the Gauss method, the average particle size was calculated through the Curve Expert tool, employing Equation 3.

$$X = c \sqrt{\frac{\frac{a}{Tm}}{0.5}} + b \quad (3)$$

Where: X is the average particle size, a, b, and c are the parameters of the Gauss model, Tm is the Y value in 50% for Equation 1, and Ln is the natural log. In this way, values were replaced in Equation 3, obtaining the following calculation:

$$\begin{aligned} X &= (1.99 \times 10^3) \sqrt{\frac{\ln\left(\frac{8.47 \times 10^5}{50}\right)}{0.5}} - 8.17 \times 10^3 \\ &= 611.937 \mu\text{m} \end{aligned}$$

The average particle size of coffee husk provided by the federation of coffee growers of the Ocaña city, Norte de Santander is 611.937 μm, compared with another study that the samples are smaller since in the threshing process is possible to obtain different particle sizes such as 4.51 to 1.428 mm [23].

3.4. Analysis of Coffee Husk in SEM

Figures 4 and 5 present the micrographs where micro

internal cracks are observed in the coffee husk after drying, which are not visible to the human eye. The composition of carbon and oxygen is evidenced, in addition to showing the structure composed of natural fibers, being cellulose, and lignin it's main, which influence the mechanical resistance that contributes to any material used in architecture construction and civil engineering [12].

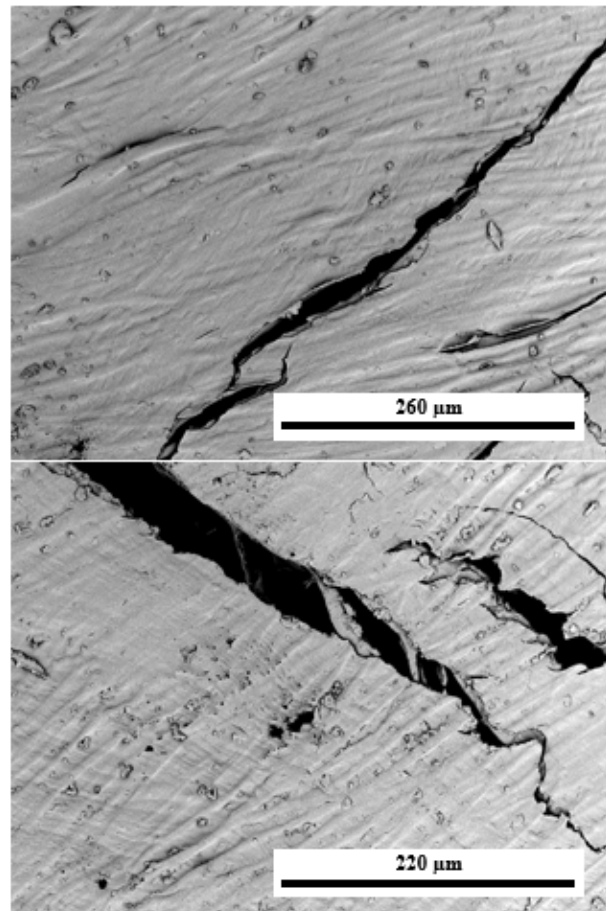


Figure 4. Micro cracks in coffee husk

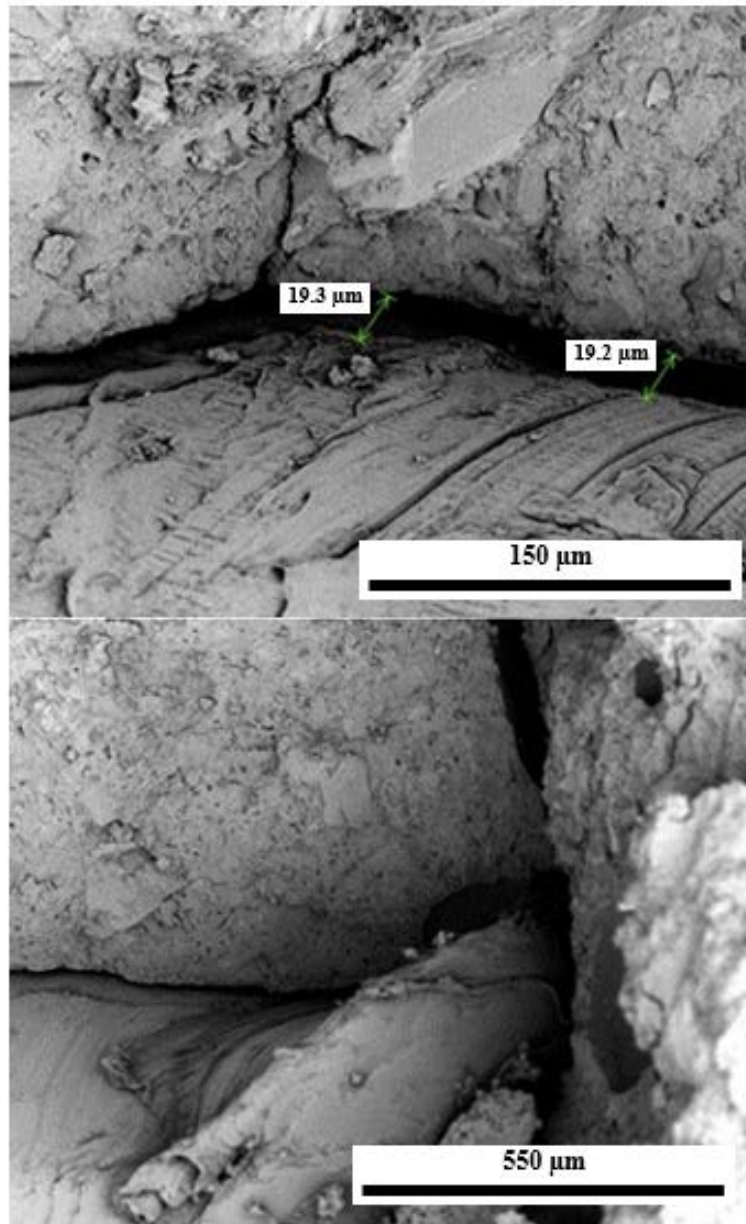


Figure 5. Micro cracks and coffee husk fibers

Notice that on average the cracks are $\sim 19 \mu\text{m}$ with excellent resistance without the evidence of the samples fracture, which allows concluding that the coffee husk can be a potential alternative for sustainable construction.

4. Conclusions

The granulometric materials composition knowledge and the use of agro-industrial waste are important for the engineering study applied to sustainable construction. This use can be considered as an alternative to aggregate materials in concrete production. The particle size of the coffee husk is related to the threshing process, where the by-product is obtained, which can have different sizes and, according to the application, exerts a great influence on its

performance.

The results obtained in the research allow to identify the coffee husk characteristics of the production of Ocaña, Norte de Santander, which has a percentage of humidity of 13.3% and an average particle size of $611.937 \mu\text{m}$; In addition, it was observed in the analyses carried out in the SEM that coffee husk is composed of natural fibers, which influence the strength of the materials, so it is concluded that coffee husk can be an alternative in sustainable construction, by weight, size, renewable source (agro-industrial waste) and natural fibers present in the by-product.

This research also bets on innovation in the creation of new materials that are environmentally friendly and resinified, thus allowing the incursion from the circular economy of materials, giving a new life to implementing

eco-materials applied to the areas of architecture, engineering, and construction of different civil applications.

REFERENCES

- [1] R. P. Munirwan, A. Mohd Taib, M. R. Taha, N. Abd Rahman, and M. Munirwansyah, "Utilization of coffee husk ash for soil stabilization: A systematic review," *Phys. Chem. Earth, Parts A/B/C*, vol. 128, p. 103252, 2022, doi: <https://doi.org/10.1016/j.pce.2022.103252>.
- [2] P. Ricciardi, F. Torchia, E. Belloni, E. Lascaro, and C. Buratti, "Environmental characterisation of coffee chaff, a new recycled material for building applications," *Constr. Build. Mater.*, vol. 147, pp. 185–193, 2017, doi: <https://doi.org/10.1016/j.conbuildmat.2017.04.114>.
- [3] A. Gedefaw, B. Worku Yifru, S. A. Endale, B. T. Habtegebreal, and M. D. Yehualaw, "Experimental Investigation on the Effects of Coffee Husk Ash as Partial Replacement of Cement on Concrete Properties," *Adv. Mater. Sci. Eng.*, vol. 2022, no. 6, pp. 152–158, 2022, doi: [10.1155/2022/4175460](https://doi.org/10.1155/2022/4175460).
- [4] S. A. Bekalo and H. W. Reinhardt, "Fibers of coffee husk and hulls for the production of particleboard," *Mater. Struct. Constr.*, vol. 43, no. 8, pp. 1049–1060, 2010, doi: [10.1617/s11527-009-9565-0](https://doi.org/10.1617/s11527-009-9565-0).
- [5] G. Canet Brenes *et al.*, *The situation and trends of coffee production in Latin America and the Caribbean*. 2016.
- [6] R. Rathinavelu and G. Graziosi, "Possible alternative uses of coffee residues and by-products," *Organ. Int. del Café*, no. 942, pp. 1–4, 2005, [Online]. Available: <http://www.ico.org/documents/ed1967c.pdf>.
- [7] W. Acchar, E. J. V. Dultra, and A. M. Segadães, "Untreated coffee husk ashes used as flux in ceramic tiles," *Appl. Clay Sci.*, vol. 75–76, pp. 141–147, 2013, doi: [10.1016/j.clay.2013.03.009](https://doi.org/10.1016/j.clay.2013.03.009).
- [8] M. Saberian *et al.*, "Recycling of spent coffee grounds in construction materials: A review," *J. cl*, 2021.
- [9] F. A. Salazar Gallego, "Colombian Coffee, analysis of the world's main coffee producers," Universidad Pontificia Bolivariana, 2021.
- [10] FNCC, "Colombian coffee production in 2019 closed at 14.8 million bags," *WebPage*, 2019. <https://federaciondefeferos.org/wp/listado-noticias/produccion-de-cafe-de-colombia-cerro-el-2019-en-148-millones-de-sacos/>.
- [11] N. Rodríguez Valencia and D. Zambrano Franco, "Coffee by-products: renewable energy source," *Av. Técnicos Cenicafé*, no. 3, Colombia, 2010. [Online]. Available: biblioteca.cenicafe.org/bitstream/10778/351/1/avt0393.pdf
- [12] J. A. Barrera López and P. F. Sánchez Velandia, "Evaluation of coffee husk as a substitute for fats used in the preparation of brownies." Universidad de los Andes, 2020, [Online]. Available: <http://hdl.handle.net/1992/44612>.
- [13] J. Ahmad and Z. Zhou, "Mechanical Properties of Natural as well as Synthetic Fiber Reinforced Concrete: A Review," *Constr. Build. Mater.*, vol. 333, no. December 2021, p. 127353, 2022, doi: [10.1016/j.conbuildmat.2022.127353](https://doi.org/10.1016/j.conbuildmat.2022.127353).
- [14] C. G. Prabhakar, K. Anand Babu, P. S. Kataraki, and S. Reddy, "A review on natural fibers and mechanical properties of banyan and banana fibers composites," *Mater. Today Proc.*, vol. 54, pp. 348–358, 2022, doi: [10.1016/j.matpr.2021.09.300](https://doi.org/10.1016/j.matpr.2021.09.300).
- [15] P. Kumar, P. Gautam, S. Kaur, M. Chaudhary, A. Afreen, and T. Mehta, "Bamboo as reinforcement in structural concrete," *Mater. Today Proc.*, vol. 46, pp. 6793–6799, 2021, doi: [10.1016/j.matpr.2021.04.342](https://doi.org/10.1016/j.matpr.2021.04.342).
- [16] Z. Zhang, S. Liu, F. Yang, Y. Weng, and S. Qian, "Sustainable high strength, high ductility engineered cementitious composites (ECC) with substitution of cement by rice husk ash," *J. Clean. Prod.*, vol. 317, no. March, p. 128379, 2021, doi: [10.1016/j.jclepro.2021.128379](https://doi.org/10.1016/j.jclepro.2021.128379).
- [17] M. Bouasker, N. Belayachi, D. Hoxha, and M. Al-Mukhtar, "Physical characterization of natural straw fibers as aggregates for construction materials applications," *Materials (Basel)*, vol. 7, no. 4, pp. 3034–3048, 2014, doi: [10.3390/ma7043034](https://doi.org/10.3390/ma7043034).
- [18] S. M. Hejazi, M. Sheikhzadeh, S. M. Abtahi, and A. Zadhoush, "A simple review of soil reinforcement by using natural and synthetic fibers," *Constr. Build. Mater.*, vol. 30, pp. 100–116, 2012, doi: [10.1016/j.conbuildmat.2011.11.045](https://doi.org/10.1016/j.conbuildmat.2011.11.045).
- [19] R. P. Munirwan, D. Sundary, Munirwansyah, and Bunyamin, "Study of coffee husk ash addition for clay soil stabilization," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1087, no. 1, p. 12016, 2021, doi: [10.1088/1757-899X/1087/1/012016](https://doi.org/10.1088/1757-899X/1087/1/012016).
- [20] A. Gedefaw, B. Worku Yifru, S. A. Endale, B. T. Habtegebreal, and M. D. Yehualaw, "Experimental Investigation on the Effects of Coffee Husk Ash as Partial Replacement of Cement on Concrete Properties," *Adv. Mater. Sci. Eng.*, vol. 2022, p. 4175460, 2022, doi: [10.1155/2022/4175460](https://doi.org/10.1155/2022/4175460).
- [21] A. A. M. Damanhuri, A. M. H. S. Lubis, A. Hariri, S. G. Herawan, M. H. I. Roslan, and M. S. F. Hussin, "Mechanical properties of rice husk ash (RHA) brick as partial replacement of clay," *J. Phys. Conf. Ser.*, vol. 1529, no. 4, p. 42034, 2020, doi: [10.1088/1742-6596/1529/4/042034](https://doi.org/10.1088/1742-6596/1529/4/042034).
- [22] NTC-2441, *Method for determination of average particle size by granulometric distribution*. Colombia, 2011, pp. 1–45.
- [23] A. C. Llanos Ramírez and A. Pérez Montealegre, "Use of coffee husks as raw material for the development of a functional biocomposite." Universidad Autónoma de Occidente, 2021.