Mix Sustentável

Chemical, physical and mineralogical characterization of Cariri stone lamination waste

Caracterização química, física e mineralógica dos resíduos da laminação da pedra Cariri

Caracterización química, física y mineralógica de los residuos del laminado de la piedra Cariri

Miguel Adriano Gonçalves Cirino[1]
Ana Verônica Gonçalves Borges[2]
Bruno Luis Damineli[3]
Paulo Manuel dos Santos Pereira de Almeida[4]
Daniel Bernardes Silva[5]

[1] Universidade Regional do Cariri, Juazeiro do Norte, Ceará, Brasil. Universidade de Lisboa, Lisboa, Portugal. Universidade de São Paulo, São Carlos, São Paulo, Brasil.

[2] Universidade Federal do Cariri, Brasil. Universidade de São Paulo.

[3] Universidade de São Paulo, São Carlos, São Paulo, Brasil.

[4] Universidade de Lisboa, Lisboa, Portugal.

[5] Universidade Federal do Cariri, Juazeiro do Norte, Ceará, Brasil.

Correspondence to: miguel.goncalves@urca.br

ORIGINAL ARTICLE - SCIENTIFIC SECTION

RESPONSIBLE EDITORS:

Lisiane Ilha Librelotto e Paulo Cesar Machado Ferroli

SUBMITTED ON
06/01/2026
ACCEPTED ON
08/09/2026
PUBLISHED ON
30/10/2026

PID
10.29783/2447-3073.MIX2026.v12.n4.263-290

Standard License Text
This work is licensed under a Creative Commons Attribution 4.0 International License.

Copyright Statement
Authors retain the copyright and grant the journal the right of first publication, with the work simultaneously licensed under a Creative Commons Attribu tion license, which permits sharing of the work with proper acknowledgment of authorship and initial publication in this journal.

Abstract: The extraction and processing of Pedra Cariri, in the southern region of Ceará, Brazil, generates large volumes of waste due to the low utilization rate of laminated limestone, with average losses reaching 70%, which have accumulated in quarry areas since the 1970s. These Pedra Cariri Wastes (PCW) represent a significant environmental liability; however, they also present important potential for technological applications in the construction industry. In this context, the objective of this research was to analyze the production and processing of Pedra Cariri and to characterize the chemical, physical, and mineralogical properties of its waste, aiming at applications in alternative cementitious materials. The methodology involved a literature review, interviews with local producers, and waste collection from quarries located in Nova Olinda, Ceará, Brazil. The samples were subjected to X-ray Fluorescence (XRF), X-ray Diffraction (XRD), Thermogravimetric Analysis (TGA), Scanning Electron Microscopy (SEM), as well as physical and granulometric analyses. The results revealed a lack of updated information regarding production and waste generation, low technological innovation, and the absence of large-scale reuse applications. The characterization indicated predominance of calcite, high CaO content, low plasticity, and fine particle size distribution. It was concluded that Pedra Cariri waste presents technological feasibility for alternative applications in civil construction, contributing to the reduction of environmental impacts.

Keywords: Pedra Cariri Wastes; Characterization Pedra Cariri Wastes; Potential technological applications.

Resumo: A exploração e beneficiamento da Pedra Cariri, na região sul do Ceará, gera elevados volumes de resíduos devido ao baixo aproveitamento do calcário laminado, com perdas médias de até 70%, acumuladas nas áreas de jazidas desde a década de 1970. Esses resíduos constituem um importante passivo ambiental, mas apresentam potencial para aplicações tecnológicas na construção civil. Nesse contexto, o objetivo desta pesquisa foi analisar o processo produtivo da Pedra Cariri e caracterizar as propriedades químicas, físicas e mineralógicas dos resíduos, visando seu uso em materiais cimentícios alternativos. A metodologia envolveu revisão bibliográfica, entrevistas com produtores locais e coleta de resíduos em jazidas no município de Nova Olinda-CE. As amostras foram submetidas a ensaios de Fluorescência de Raios X (FRX), Difração de Raios X (DRX), Termogravimetria (TG), Microscopia Eletrônica de Varredura (MEV), além de análises físicas e granulométricas. Os resultados evidenciaram ausência de dados atualizados sobre produção e geração de resíduos, baixa inovação tecnológica e inexistência de aplicações em larga escala. A caracterização revelou predominância de calcita, elevado teor de CaO, baixa plasticidade e granulometria fina. Conclui-se que os resíduos da Pedra Cariri apresentam

Conflict declaration
Nothing to declare.

Funding source
This research was supported by CNPq/MCTI Universal Call 2023, FAPERGS Call 09/2023 - Gaúcho Researcher Program, and FAPERGS Call 10/2024 - ARD/ARC.

viabilidade tecnológica para aplicações alternativas na construção civil, contribuindo para a redução dos impactos ambientais.

Palavras-chave: Resíduos da Pedra Cariri; Caracterização dos Resíduos da Pedra Cariri; Edificac;ao; Potencial aplicação tecnológica.

Resumen: Este artfculo presenta los resultados de la aplicaci6n de la herramienta USAT (Urban Sustainability Assessment Tool), creada para la gesti6n de la sostenibilidad a escala urbana y edilicia. El sitio del estudio de caso es la Lagoa da Conceic;;ao, en Florian6polis. Estos indicadores fueron organizados en categorias para evaluar la estructura urbana y las edificaciones segun el Modelo ESA-B. En total, el sistema presenta cuatro paneles: Choques, Estructura Urbana, Conducta y Desempefio. En este artfculo se presentan los datos del Panel de Estructura Urbana, a partir del analisis del distrito de Lagoa da Conceic;;ao, y del Panel de Conducta, con el analisis de una edificaci6n comercial ubicada en el barrio. La investigaci6n contribuye a la sostenibilidad urbana al ofrecer una estructura de gobernanza para el area de estudio, con potencial de ser replicada en otras regiones con desaffos similares. La explotación y el procesamiento de la Piedra Cariri, en la región sur del estado de Ceará, Brasil, generan grandes volúmenes de residuos debido al bajo aprovechamiento de la piedra caliza laminada, con pérdidas promedio de hasta el 70 %, acumuladas en las áreas de extracción desde la década de 1970. Estos Residuos de Piedra Cariri (RPC) representan un importante pasivo ambiental; sin embargo, presentan un significativo potencial para aplicaciones tecnológicas en la construcción civil. En este contexto, el objetivo de esta investigación fue analizar la producción y el beneficiamiento de la Piedra Cariri, así como caracterizar las propiedades químicas, físicas y mineralógicas de sus residuos, con el fin de evaluar su aplicación en materiales cementicios alternativos. La metodología incluyó revisión bibliográfica, entrevistas con productores locales y recolección de residuos en canteras ubicadas en Nova Olinda, Ceará, Brasil. Las muestras fueron sometidas a ensayos de Fluorescencia de Rayos X (FRX), Difracción de Rayos X (DRX), Análisis Termogravimétrico (TG), Microscopía Electrónica de Barrido (MEB), además de análisis físicos y granulométricos. Los resultados evidenciaron la ausencia de información actualizada sobre la producción y generación de residuos, baja innovación tecnológica y falta de aplicaciones a gran escala. La caracterización mostró predominancia de calcita, alto contenido de CaO, baja plasticidad y granulometría fina. Se concluye que los residuos de Piedra Cariri presentan viabilidad tecnológica para aplicaciones alternativas en la construcción civil, contribuyendo a la reducción de los impactos ambientales.

Palabras clave: Residuos de piedra Cariri; Caracterización de los residuos de piedra Cariri; Edificación; Potencial aplicación tecnológica.

Como citar: CIRINO, Miguel Adriano Gonçalves; BORGES, Ana Verônica Gonçalves; DAMINELI, Bruno Luis; ALMEIDA, Paulo Manuel dos Santos Pereira de; SILVA, Daniel Bernardes. Caracterização química, física e mineralógica dos resíduos da laminação da pedra Cariri. **Chemical, physical and mineralogical characterization of Cariri stone lamination waste.** Florianópolis, v. 12, n. 4, p. 263-290, 2026. DOI: 10.29783/2447-3073.MIX2026.v12.n4.263-290.

1 INTRODUCTION

The mining of Cariri Stone represents one of the main mineral activities in the southern region of Ceará, especially in the municipalities of Nova Olinda and Santana do Cariri. In addition to its economic and social importance for the region, this activity has strong geological, cultural, and paleontological relevance due to Cariri Stone's location within the Araripe Sedimentary Basin, recognized worldwide for its fossil richness and diversity of mineral resources.

The Cariri region is an urban agglomeration located in the south of the state of Ceará, consisting of important cities in the context of Ceará, the Northeast, and Brazil, with particular emphasis on the cities of Juazeiro do Norte, Crato, and Barbalha. The region shows strong economic growth, particularly in manufacturing, culture, commerce, tourism, and education (ANUÁRIO CEARÁ, 2025).

The Cariri region encompasses a diversity of natural landscapes and is characterized by a great wealth of mineral resources, especially limestone, which is extracted for various purposes, including the production of ornamental rocks and use in the construction sector. Cariri is a strategic region, not only for its economic importance, but also for its significant paleontological value, due to its fossils and geological formations that attract the attention of researchers and tourists.

The geological history of the Araripe Basin began approximately 150 million years ago, corresponding to the Upper Jurassic Period in the Mesozoic era, when the region was a vast depression on the Earth's surface. This period includes the separation of the supercontinent Gondwana, a fact that contributed to the formation of sedimentary basins in Brazil, such as the Araripe Sedimentary Basin.

The Araripe Basin has great potential for the exploration of mineral resources, such as laminated limestone, gypsum, clay, and mineral water. Laminated limestone, known as "Pedra Cariri," has been mined since the 1970s and is widely used in civil construction and architecture in the Cariri region (LIMA et al, 2011).

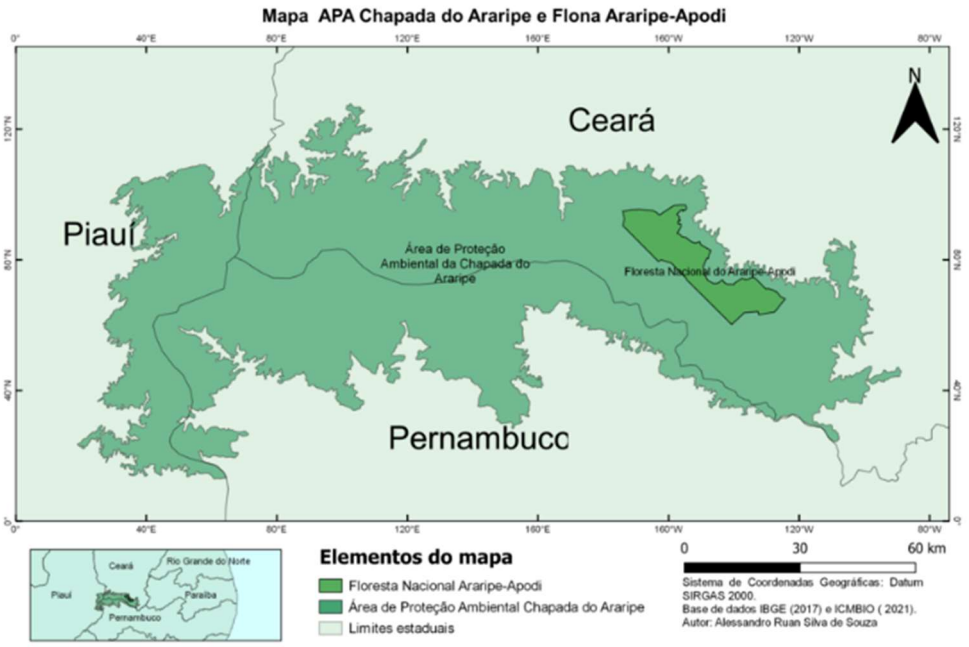
The Araripe sedimentary basin is in the Transversal Zone, a large belt with geological faults and fractures that extends from east to west, from the coast of Paraíba and Pernambuco to Piauí, where it is covered by layers of sedimentary rocks from the Parnaíba Basin (PONTE & PONTE FILHO, 1996).

During this period, according to Vidal et al. (2008), there was the opening of the South Atlantic Ocean and intense tectonic activity, which generated the supercontinent Pangaea, forming large depressions, associated with climate changes, and rivers transported and deposited large quantities of rock fragments, sand, mud, as well as plant and animal material from higher mountainous areas (ASSINE, 2007).

According to Vidal and Padilha (2003), the Araripe Sedimentary Basin is one of the largest sedimentary basins in Brazil, with an area of approximately 9,000 km², extending 180 km east to west and 70 km north to south, encompassing the states of Ceará, Paraíba, Pernambuco, and Piauí (Figure 1).

Among the technical, economic, and environmental challenges faced by the exploration and processing of Cariri Stone are threats to fossil resources of global importance.

Figure 1 - Geographic location of the Araripe sedimentary basin



Source: SOUZA and BEZERRA, 2022.

The fossil heritage is relevant not only for its diversity, but also for the quality of preservation of the findings, such as the observation of the first fossil records of soft tissues of pterosaurs (considered the main global concentration of these flying reptiles) and dinosaurs found in the world, and transitional forms between gymnosperms and angiosperms (VIDAL et al., 2008; DILCHER et al., 2005; HERZOG et al., 2008 and BACCI et al., 2009).

The Cariri Metropolitan Region presents a complex scenario of waste generation, with emphasis on the footwear, costume jewelry, ceramic, and mineral sectors.

In this context, the mineral sector is considered one of the main generators of waste volumes in the Cariri region (ALENCAR- LINARD; LIMA; SAEED-KHAN, 2015). Cariri Stone (laminated limestone), extracted mainly in Nova Olinda and Santana do Cariri, is defined as an ornamental rock due to its aesthetic and resistance properties (SILVA et al., 2008). Geologically, it is part of the Crato Member of the Santana Formation, composed of sedimentary layers approximately 112 million years old (LIMA et al., 2011).

Cariri Stone is a simple mineralogy, composed of laminated limestones, predominantly formed by calcite [CaCO3], dolomite [CaMg (CO3)2] and secondary minerals, such as anhydrite [CaSO4], gypsum [CaSO4.2H2O], siderite [FeCO3], among other mineral compounds in smaller quantities. This rock has a sedimentary origin, arranged in thin layers of sediments belonging to the Crato Member (Santana Formation),

deposited approximately 112 million years ago (Cretaceous Period), when there was a lake of calm waters in the region, with marshes on its banks, conducive to the development of abundant biodiversity (LIMA et al., 2011; NEIVA et al., 2018).

In terms of reserves, according to Vidal and Padilha (2003), the Cariri region has approximately 97 million cubic meters, equivalent to 241 million tons, according to data from the DNPM (National Department of Mineral Production), mainly covering the municipalities of Santana do Cariri and Nova Olinda.

In terms of importance not only from a mineralogical and commercial standpoint but also from an environmental point of view, due to its special characteristics and because of the risks associated with mining activity and the need to protect the region's material heritage, and to prevent clandestine and irregular exploitation, the first national park protected by federal law (Decree Law 9226), the Araripe National Forest, Figure 4, was created in 1946, with a protection area of 38,262 hectares (VIDAL et al., 2008).

Thus, the research aims to analyze the Cariri stone production sector and the technological characterization of Cariri stone waste, aiming at technological applications in the civil construction and architecture sectors.

Technological characterization, regarding chemical, physical, and mineralogical properties, is considered the primary step for application studies aimed at producing higher quality materials and, in particular, producing alternative materials capable of adding value to waste and thus reducing the environmental impact resulting from the many years of exploitation of Cariri stone and the low level of utilization of the waste.

2 RESEARCH METHODOLOGY

The first phase of the research relates to the study of bibliographic sources, to understand the historical panorama of Cariri stone, its residues, and its applications.

To this end, an analysis was carried out. The exploratory phase aims to analyze existing information on the topic under development, serving as a basis for the state of the art, bibliographic and critical synthesis, as well as providing a foundation for the research methodology.

In the exploration phase of the research, information was gathered on architecture, tectonics, construction systems, limestone residues (Cariri Stone), construction materials and technologies, as well as properties and technical criteria for material characterization.

This data was obtained from libraries, public and private collections such as the Catalog of Theses & Dissertations (CAPES) and the Brazilian Digital Library of Theses and Dissertations (BDTD), as a starting point for approaching the topic in Brazil, in addition to university repositories and databases such as Web of Science and Science Direct, through a Systematic Bibliographic Review.

To obtain a current overview of the exploration and processing of Cariri stone, semi-structured interviews were conducted with a large producer and with the CTMC board, with questions focusing on production,

obstacles to the sector's development, sector organization and management, products and marketing, and waste management.

The interview employed a semi-structured methodology, utilizing a pre-defined set of questions and a guide, while allowing interviewees the freedom to elaborate on their answers.

The interview took place at the URCA facilities on August 20, 2026. It was conducted directly with the engineers responsible for the CTMC including the center's technical and operational lead and with the coordinator of URCA's innovation department; both parties played key roles in the CTMC's reopening and modernization.

The semi-structured interview consisted of open-ended questions regarding the CTMC's structure and production capacity; in an integrated manner; waste losses and management; product value addition; water use and reuse; emissions and environmental impacts; workforce, worker health and safety, social initiatives, and integration with public agencies and the cooperative; as well as procedures for standardization, certification, and fossil management.

The interview was recorded using an application on the interviewers' mobile phones, with the interviewees' consent. Subsequently, the material was transcribed and analyzed. The data obtained did not undergo a formal categorization process; instead, the study is framed as a descriptive qualitative analysis of CTMC activities, aimed at understanding the production structure of Cariri Stone viewed not only from the perspective of large-scale producers but also from that of small-scale producers who benefited from initial public investment.

2.1 Characterization of the Cariri stone waste

The waste from the lamination of Cariri stone comes from deposits located in the municipality of Nova Olinda, Ceará, Brazil, and was collected according to the prescriptions of the Brazilian standard ABNT NBR 10007 (2004), separated, oven-dried, and prepared for subsequent characterization analyses.

Samples of Cariri stone waste were collected at the Cariri Mineral Technology Center (CTMC) in the cutting sludge disposal area, where they were placed in bags and containers. Subsequently, the collected material was transported and stored at the Construction Materials Laboratory of the Regional University of Cariri.

The waste was collected manually, randomly, under the guidance of those responsible for the quarries. After collection, the material was placed in plastic bags and sent for storage in weatherproof deposits located on the premises of the Regional University of Cariri (URCA), in the municipality of Juazeiro do Norte, Ceará, Brazil.

Subsequently, the materials were subjected to oven drying at a temperature of 110 °C ± 5 °C for a period of 24 hours. After drying, sieving, any necessary lumps were removed, and granulometric pre-classification was performed using simple sieving.

The samples were then separated, homogenized, and weighed using a precision digital balance with a resolution of 0.01 g. At this stage, the samples were also prepared for characterization tests, according to the guidelines established in the specific technical standards for each method.

Next, the Cariri Stone Residues (RPC) were characterized in terms of chemical composition, by X-ray Fluorescence (XRF); mineralogical composition, by X-ray Diffraction (XRD); thermal behavior, by thermogravimetric analysis (TG); particle morphology, by Scanning Electron Microscopy (SEM); in addition to the determination of specific gravity, moisture content and granulometric analysis, as presented in Table 1.

Table 1 - Physical, chemical, and mineralogical characterization of Cariri stone waste.

Essays	Normative Reference	Justification for the Essay
X-ray Fluorescence (XRF)	ABNT NBR 14656:2023	Chemical composition and composition of ligands
X-ray Diffraction (XRD)	ABNT NBR 14656:2023	Polycrystalline phases of materials
Thermogravimetry (TG)	Non-standardized	Sintering temperature and quantification of CO_2 emissions
Scanning Electron Microscopy (SEM)	Non-standardized	Morphology and particle size distribution of materials
Specific Mass	ABNT NBR 16916:2021	Replacement of natural materials and production of binders.
Moisture Content	ABNT NBR 9775:2011 – Fine aggregate	Correction of the mix design.
Atterberg Limits	ABNT NBR 6457: 2024 – Preparation; ABNT 6459: 2025 – LL; ABNT NBR 7180: 2025– LP.	Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI = LL - PI)
pH Dry and real density		Hydrogen Potential – testing the acidity and basicity of the residue.
Water absorption	ABNT NBR 16916:2021	
Particle Size Analysis	ABNT NBR 17054:2022 and ABNT NBR 16973:2021	Particle size distribution of materials to produce binders, aggregates, and *fillers*.

Source: prepared by the authors.

a) Chemical composition (XRF): The main oxides present in the samples were determined by XRF analysis. For the test, the ZSXMini II – Rigaku equipment for quantifying elements from Fluorine to Uranium, belonging to the Physics Department of UFC, was used.

b) Moisture content: The moisture content expresses the amount of water present in the sample, being an

important parameter for application in cementitious compounds. Both tests were carried out in the Materials and Civil Construction laboratory at URCA.

c) Specific Gravity: The specific gravity was determined following standard procedures and was carried out in the Materials and Civil Construction laboratory at URCA.

d) Loss on ignition: Loss on ignition indicates the residual mass of carbon in the residues and inert substances present in calcium carbonate. This is an important parameter for determining the quality of the material and for quantifying carbon dioxide emissions. The test was carried out in the chemical analysis laboratories of URCA.

e) Determination of particle size distribution (Fineness by Blaine method and laser granulometry): This test aims to evaluate the specific surface area of the material and the uniformity of the particles in the grinding or production process of the material, and can be related to the particle size distribution, shape and fineness of the grains, and is related to the reactivity and interaction between particles of the material [44]. For the determination of the particle size distribution of CCCM, the CILAS laser granulometer was used 920L from the Federal University of Paraíba (UFPB).

f) Morphological characterization (SEM): A HITACHI TM 3000 scanning electron microscope with an EDS SWIFT ED 3000 coupled peripheral, from the Physics Department of URCA, was used.

g) Thermal analysis (TG and TGA): Equipment belonging to the Materials Characterization Laboratories of the Federal University of Cariri (UFCA) was used. Samples were weighed with masses between 10 mg and 15 mg, placed in an alumina crucible, and tested using Shimadzu equipment. DTG-60, with a heating rate of 10°C /min, with a nitrogen atmosphere, a flow rate of 100 ml /min, and a temperature range from ambient (approximately 22°C) to a maximum temperature of 900°C, and the TA application was used to obtain the curves for the thermal analyses. universal analysis [45].

h) Mineralogical analysis (XRD): To identify the polycrystalline phases present in the samples, a Shimadzu X-ray diffractometer – model 7000, with a 60W and 100-240 V 50/60 Hz X-ray tube, with a scan between 5° and 80° (in 2 Θ), pass size of 0.02°, belonging to the Physics Laboratory of UFC, was used.

2.2 Impacts related to the circular economy of Cariri Stone

In the environmental context, the mining and processing of Cariri stone presents strong pressure on the circular economy in the Cariri region, with risks associated with environmental, social, economic, and Brazilian fossil heritage issues.

Among the products marketed, material waste is estimated at around 70% on average, depending on the extraction method. Semi-mechanized and, in periods of lower mechanization rates or among small producers, in manual processes, losses reached 90% of the extracted material (VITAL e PADILHA, 2003).

In terms of the use of Cariri stone waste, especially cutting waste, which forms the "Cariri stone mud," a small portion was used in the production of Portland cement in an industry located in the city of Barbalha –

Ceará. However, as the cement industry ceased operations in 2004, the waste no longer had a significant volume of use and was deposited in the mining areas, becoming a significant environmental liability in the Cariri region.

Regarding informality and management in the sector, a marked structure is observed. by small businesses with low technological integration and management difficulties. Many of these are linked to local cooperatives managed by large producers who obtain financing lines to acquire more efficient equipment and, thus, control the cooperatives and make decisions that primarily benefit their own interests.

In the context of exploration and processing of Cariri stone, following the creation of the Cariri Stone Local Productive Arrangement (APL) in the 2000s, the Cariri Mineral Technology Center (CTMC) emerged in 2018. The project envisioned the self-financing of the CTMC, with initial investment coming from public funds, and focused on processing Cariri stone for small and medium-sized producers who paid a fixed amount of R$ 5.00 per square meter processed.

In this situation, according to the director, as of 2026, the prices charged were not sufficient to cover the basic operating costs of the Cariri stone quarry, which led to the closure of operations at the end of 2023. It was pointed out that, in 2020, CTMC was operating at 11% of its production capacity, and pressure began to mount on small producers to process the materials in larger industries.

Thus, the costs became prohibitive for maintenance and innovation through the acquisition of more efficient machines, which led CTMC to adjust its business plan and it is currently in this business adjustment phase.

As of August 2026, the CTMC was equipped with two calibrators, two squaring machines, and three edge-trimming machines, with a historical production capacity of approximately 100 m²/day. A single-head polisher and a hydraulic press were in the process of being acquired, aiming to improve finish quality, reduce waste, and enable the production of higher value-added materials.

Waste utilization was limited, focusing primarily on larger offcuts produced by the edge-trimming machines. Sludge, dust, irregular pieces, and small fragments were neither systematically reused nor quantified. The greatest losses occurred during mining and cutting stages, particularly in manual or semi-mechanized processes. Boulders currently underutilized were identified as having potential for higher value-added products.

Process water was recirculated, undergoing sedimentation and filtration before returning to the production line. Electrical equipment did not generate significant gaseous emissions, although particulate matter was produced during cutting.

Regarding the social and institutional dimension, the CTMC maintained partnerships with the municipal government and the cooperative and had already conducted mosaic workshops using CSW (RPC) . There is potential to expand these initiatives through integration with university courses, particularly Architecture.

The direct workforce was small, with one employee responsible for CTMC maintenance and

organization, while production was carried out primarily by workers linked to mining companies. Training on equipment use and the use of personal protective equipment (PPE) was provided, but there was no systematic monitoring of workers' health conditions.

Finally, any fossils discovered during mining or at the CTMC had to be reported and forwarded to the responsible agencies and institutions, such as the URCA Geopark and the Paleontology Museum. Overall, the CTMC shows potential to reduce waste and enhance the value of Cariri Stone waste; however, it needs to improve quantitative waste tracking and production management, while steering its activities toward the development of higher value-added products and circular economy practices.

In terms of job creation, mining Cariri stone is vital to the local economy, generating approximately 1,500 direct and 4,000 indirect jobs in Nova Olinda and Santana do Cariri (VIDAL; FERNANDES; PEQUENO, 2007). Of this total, most jobs involve professions that require less technical qualification, and thus, low pay is common in the sector.

Regarding financial matters, producers stated that the product is sold at a low price of approximately R$ 22.00/m² for the most in-demand product, the 50 cm x 50 cm tiles, which are sold for R$ 35.00 to R$ 45.00 in the local market of Juazeiro do Norte.

Thus, large producers seek to diversify consumer markets and offer differentiated products with higher added value, featuring diverse surface treatments, different shapes and sizes, and applications in flooring and wall coverings.

Larger companies provide training, use personal protective equipment, and employ more modern equipment for handling and transporting parts, which causes less harm to workers' health. In contrast, small producers face less stringent safety measures, directly impacting not only the materials produced but also posing risks to the health of their employees.

According to data presented by Nunes (2015), who analyzed the health data of workers for a sample of 272 workers, the vast majority have low levels of education, with only 9.61% literate, a lack of proper use of PPE, and a significant portion of workers have pulmonary and respiratory diseases and digestive problems, indicating the continuous need for monitoring workers directly or indirectly linked to the Cariri stone sector.

In this context, in an interview with one of the major producers, he pointed out difficulties in establishing full production or expanding exploration and processing due to the difficulty in acquiring new workers, as well as effectively retaining existing workers.

To mitigate environmental impacts and foster development, Local Productive Arrangements (APLs) and the COOPEDRAS cooperative were established. These initiatives aim to integrate science and technology to add value to limestone and promote awareness of the preservation of the paleontological heritage of the Chapada do Araripe, an area protected by the Araripe National Forest (VIDAL et al., 2008; CASELLI; GOMES, 2015).

Low efficiency in commercial use results in critical environmental liabilities. It is estimated that, in

2016 alone, the accumulated volume of waste in the municipalities of Nova Olinda and Santana do Cariri reached approximately 755,000 m³ (VIDAL; PADILHA; OLIVEIRA, 2006).

The main actions for utilizing waste materials are sporadic and stem from academic research, lacking large-scale initiatives. Finally, the context of Cariri stone mining and processing lacks updated fundamental data for planning waste management actions, as there is no control or updating of annual mining data, environmental impact monitoring, periodic analyses of water bodies, air quality, noise, and societal impacts. Furthermore, there is no updated data on waste generation by producer type, nor on the amount of residual material and the recovery of degraded areas.

3 METHODOLOGY FOR EXTRACTING AND PROCESSING CARIRI STONE

Table 2 presents, in a concise manner, the main stages of the extraction and processing of Cariri stone. For each phase, the fundamental activities are described, accompanied by the respective photographic records and bibliographic sources used, providing an overview of the production process, from quarrying to final processing in the sawmills.

Table 2 - Physical, chemical, and mineralogical characterization of Cariri stone waste

Step and Brief description	Figures
Figure 2 - Open-pit mining. Extraction via countertops in a lounge-style format, with lateral and depth extension. **Source:** Carvalho Neta, 2019.	
Figure 3 - Removing the cover. Removal of vegetation, clay soil, and weathered limestone until consolidated limestone is reached. Source: Pereira, 2019.	
Figure 4 - Cleaning the area. Use heavy machinery for removing topsoil and preparing the mining area. **Source:** Rodrigues And Gurgel, 2018.	
Figure 5 - Waste separation. Manual or mechanical removal of defective panels and accumulated debris in the area. **Source:** Mendes Filho, 2009.	

Figure 6 - Mechanized cutting. Use of machines with diamond blades for initial cutting of the panels. **Source:** Rodrigues and Gurgel, 2018.	
Figure 7 - Cutting the panels. Cutting the rolled limestone into regular grids using water to reduce dust. **Source:** Vidal et al., 2008.	
Figure 8 - Manual separation. Removal of the plates using levers, taking advantage of the natural cleavage planes. **Source:** Vidal et al., 2008.	
Figure 9 - Hand-finished. Manual adjustment and separation of the panels using spatulas and a hammer. **Source:** Nunes, 2015.	
Figure 10 - Final processing. Shaping the panels to the comercial dimensions required by customers. **Source:** Pereira, 2019.	

Source: organized by the authors.

It is observed that the extraction and processing of Cariri stone involves successive stages of quarrying, cutting, separation, and processing of the limestone slabs. The different stages involve a combination of manual and mechanized methods. Due to the technology employed, significant waste is generated. Thus, the processing of Cariri stone can be characterized as semi-mechanized, directly dependent on the geological conditions of the outcrop, the size of the mining industry, and the operational experience of the workers.

4 ARCHITECTURAL TYPOLOGY AND APPLICATIONS OF CARIRI STONE AND ITS RESIDUES

Unlike other ornamental rocks that use explosives and deep drilling, the extraction of Pedra Cariri is characterized by selective and mechanized dismantling. This method uses specific equipment for cutting and handling the rocks, preserving the integrity of the laminated layers (SAMPAIO; ALMEIDA, 2008).

The waste produced: The shaping process generates two main physical states of waste: chips and sludge (GONÇALVES, 2000). For study purposes, these materials are classified into four categories based on their production origin (Table 3).

Table 3 - Waste type of Cariri stone

Waste Type, origin and Characteristics	Figure
Figure 11 - Extraction (Blocking). Irregular fragments generated at the mining face during the separation of larger blocks.	
Figure 12 - Cut and Scraps. Leftover irregular shapes result from cutting sheets into commercial sizes.	
Figure 13 - Sawdust (Powder). Fine particles (dry dust or abrasive mud) resulting from surface finishing.	
Figure 14 - Polishing (Limestone Sludge). An aqueous suspension of fine abrasive calcium carbonate particles, generated to mitigate dust.	

Source: prepared by the authors.

The waste generated in the extraction and processing of Cariri stone presents distinct characteristics depending on the production stages and the equipment used. In the extraction stage, called blocking, irregular fragments are produced from the detachment of larger blocks at the quarry face. In the cutting and shaping of

slabs, scraps and leftovers of irregular shapes are generated, resulting from adapting the pieces to the dimensions for commercialization.

In the sawing stage, fine particles in the form of dry powder are produced, forming an abrasive slurry, resulting from the surface finishing of the plates. In the polishing stage, a so-called limestone slurry is formed, with the addition of water to prevent the release of airborne material and to cool the equipment; this slurry is composed of an aqueous suspension of fine calcium carbonate particles.

In many cases, some pieces are sold containing small fossil traces of algae and small fish, which, due to their frequency in rock formation, end up being naturally incorporated into the product being sold, for example, Figure 15. When more significant and rare fossil finds occur, these are collected and the IPHAN (National Institute of Historical and Artistic Heritage) or the DNPM (currently ANM, National Mining Agency) is notified, and in some cases, they are sent to the Paleontology Museum of the Regional University of Cariri in the city of Santana do Cariri.

Figure 15 - Scorpion fossil founded.



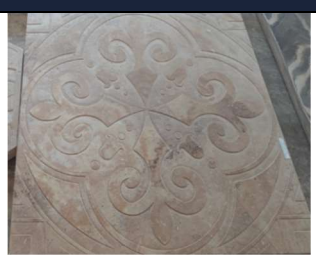
Source: prepared by the authors.

In terms of the diversity of Cariri stone products, noteworthy items include slabs for wall and floor coverings with commercial dimensions of 50 cm x 50 cm with a rustic or polished surface finish; slabs with varying dimensions of 10 cm x 10 cm and 20 cm x 40 cm; slabs with irregular shapes (organic modulation); sets of slabs in the form of mosaics; acid-treated surface with relief; furniture and decorative elements (Table 4).

Table 4 - Types of products marketed from Cariri stone

Product type	Figure
Figure 16 - Cariri stone slab 50 cm × 50 cm without polished surface finish. Source: prepared by the authors.	

Figure 17 - Cariri stone slab 50 cm × 50 cm with polished surface finish. Source: prepared by the authors.	
Figure 18 - Cariri stone slab 20 cm × 40 cm. Source: prepared by the authors.	
Figure 19 - Irregular Cariri stone slabs. Source: prepared by the authors.	
Figure 20 - Cariri stone with rustic surface finish. Source: prepared by the authors.	
Figure 21 - Cariri stone slab 10 cm × 10 cm. Source: prepared by the authors.	
Figure 22 - Cariri stone in mosaic format. Source: prepared by the authors.	

Figure 23 - Experimental Cariri stone slab surface-treated with acid. Source: prepared by the authors.	
Figure 24 - Furniture made from Cariri stone. Source: prepared by the authors.	
Figure 25 - Decorative element made with Cariri stone. Source: prepared by the authors.	
Figure 26 - Decorative panel made with Cariri stone in different shades. Source: prepared by the authors.	

Source: prepared by the authors.

Regarding waste, since there is no large-scale use, waste is evaluated in several research projects focusing on the civil construction area with applications in the production of artificial stones (Bezerra et al, 2022), production of ceramic blocks as mineral filler (Menezes et al, 2010), substitution of fine aggregate in mortars (Silva, 2008), production of mortar blocks (Guimarães, 2014), Material Filler as a substitute for cement in conventional concrete (Moura, Leite and Bastos, 2013), Mineral constituent for the production of red ceramic tiles (Barroso et al, 2016), Production of self-compacting mortars (Galvão et al, 2016), Soil replacement for the production of ecological bricks (Santos, Pereira and Bezerra (2020), Partial replacement of coarse aggregates in conventional concrete (Pereira, 2019), Production of refractory material (Dias et al, 2021), Use in granular layers in paving (Oliveira, 2016), production of calcium hydroxide (Alves, Brasileiro and Prado, 2016) and Production of aluminate cement (Batista, 2023).

All these potential uses of waste materials depend directly on research linked to universities, with little

direct interest from producers in promoting studies and feasibility analyses of large-scale waste use. Exceptions exist, such as large producers with academic experience who understand the importance and seek to support studies on the potential of Cariri stone waste.

5 CHEMICAL, PHYSICAL PROPERTIES AND MINERALOGICAL CHARACTERIZATION OF CARIRI STONE WASTE

Table 5 presents the results of the chemical composition analyses, obtained by X-ray Fluorescence (XRF), for the yellow-colored Cariri Stone Residue (CSR), indicating the levels of the main oxides, as well as a comparative overview between the values obtained in this investigation and those reported in literature.

Analysis of the chemical composition indicates that the Cariri Stone Residue (RPC), which is yellow in color, has a high CaO content (49.51%), a value commonly observed in carbonate rocks, and which confers high potential for alkaline applications.

Table 5 - Characterization of Cariri stone waste

Main oxides	Percentual (%)					
	CaO	Al2O3	SiO2	MgO	Fe2O3	Lost on fire
Results obtained	49.52	1.78	2.49	_	1.80	44.41
Correia, Vidal and Ribeiro (2008)	53.9	0.27	1.16	0.78	0.49	43.40
Menezes *et al.* (2010)	54.39	-	0.85	-	0.66	44.10
Livalter *et al*. (2008)	52.71	0.38	0.53	-	0.45	45.93
Barros *et al*. (2020)	43.34	-	1.08	2.6	0.48	46.15
Tammam *et al*. (2023)	51.97	0.82	4.93	0.58	0.58	41.12

Source: organized by the authors.

In relation to the other oxides, the levels of SiO_2 (3.49%) and Al_2O_3 (1.77%), indicating a reduced level of impurities and high purity of the limestone residue. The iron oxide (Fe_2O_3) content, at 1.80%, can be classified as moderate, while the other oxides show residual concentrations. The absence of detectable MgO is a favorable aspect regarding the volumetric stability of the material. These results are particularly relevant for technological applications, especially concerning the formulation of alternative cementitious binders from Cariri Stone residues.

The results are consistent with the bibliographic references, especially for Cariri stone, and indicate that there is variability depending on the location of the deposits, with variations in impurity levels and the presence of oxides commonly observed in dolomitic limestones.

About the comparison with the results of Barros et al. (2020) and Tammam et al. (2023), who present results from carbonate rock residues, observe a wide variety in the composition of the main oxides, especially

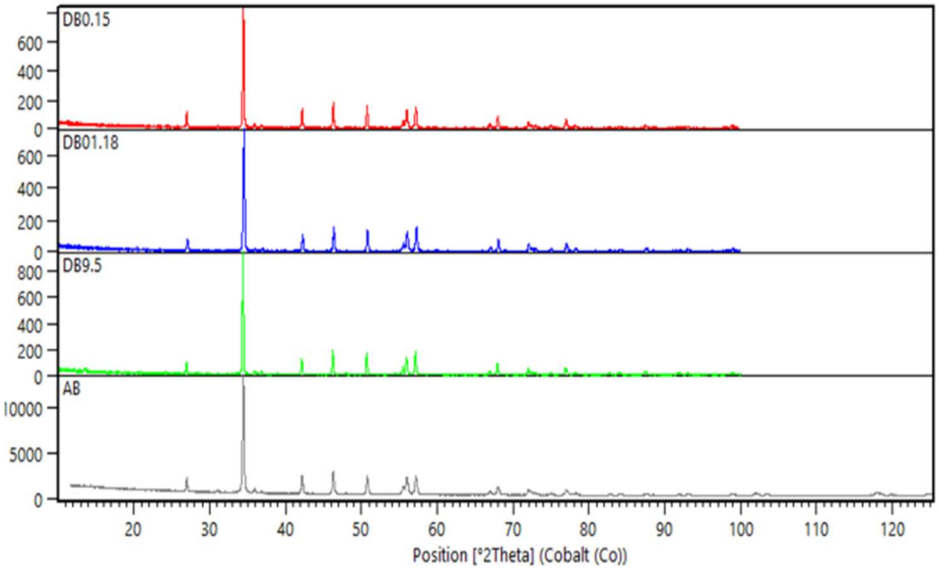
for CaO, largely depending on the impurity content, origin and geological characteristics of the material.

For the loss on ignition analysis, two types of Cariri Stone residue were evaluated, corresponding to yellow and gray colors. The results indicated a loss on ignition of 44.44% for the yellow RPC, a value associated with the significant presence of carbonates, evidenced by the decarbonation process of calcium carbonate, with the release of carbon dioxide. For the gray RPC, the loss on ignition was 43.99%, representing a small difference of approximately 1.21% compared to the yellow RPC, which indicates similar thermal behavior between the two materials.

In the development of the research, the Cariri Stone residues will be used as found in the deposits, that is, without strict distinction between the types of yellow and gray coloration and may present compositional variations between the mineralogical phases and the oxides identified.

Analysis of the diffractograms allowed for the mineralogical characterization of the Cariri Stone residues, aiming at the identification of the crystalline phases present in the samples (Figure 27). For this purpose, four samples resulting from the preparation of materials previously classified according to particle size were analyzed. The samples corresponded to the particle size fractions of 0.15 mm (represented by red), 1.18 mm (blue color), 9.5 mm (green color) and sample AB, referring to the crushed material with heterogeneous particle size distribution, represented by the color gray.

Figure 27 - Diffractogram of Cariri stone residues



Source: prepared by the authors.

In both diffractograms, crystalline phases predominantly composed of calcite (calcium carbonate) are observed, a mineral commonly associated with materials of high purity or low contamination or impurity levels. These results are consistent with those reported by Menezes et al. (2010) for the yellow-colored Cariri Stone, widely mined in the deposits of the municipality of Nova Olinda.

The analyses indicate the absence of significant variations in the intensity and position of the most energetic peaks, especially the peak at approximately 35° (2θ), as well as other peaks of lower intensity, all associated with calcite, which remain present in all samples analyzed.

In terms of physical characteristics, the results for the parameters specific mass, dry density, real density, water absorption, hydrogen potential (pH), Atterberg limits (LL – Liquid Limit, LP – Plastic Limit and IP – Plasticity Index), are presented in the Table 6.

Table 6 - Characterization of Cariri stone waste

Property	Observed value
Specific mass	2.322 g/cm³
Dry density	2.27 g/cm³
Real density	2.72 g/cm³
Water absorption	6.93%
pH	6.5
LL	23%
LP	17%
IP = (LL - IP)	6%

Source: prepared by the authors.

The physical-chemical and geotechnical characterization of the material indicates behavior compatible with that of fine residues used in construction materials. The apparent specific gravity (2.322 g/cm³) and dry density (2.27 g/cm³) show values close to each other, while the real density (2.72 g/cm³) is typical of materials with a predominance of mineral phases of calcareous nature.

A water absorption of 6.93% indicates moderate porosity, suggesting that, in certain applications, there may be an increase in water demand, with potential impacts on the durability of the material, especially in cementitious systems. Therefore, attention must be paid to the mixed design process to avoid compromising the mechanical properties of the composites produced.

The pH value of 6.5 characterizes the material as slightly acidic to neutral, indicating low chemical aggressiveness, a favorable condition for its application in cementitious materials and in processes involving sintering. Atterberg limits results, with a plasticity index (PI) of 6%, indicating reduced sensitivity to the addition of water. These results point to good dimensional stability and adequate workability of the material in different applications, such as mortars, cementitious materials in general, soil stabilization, and paving, without significant influence on sintering processes.

Overall, the results indicate that Cariri stone waste exhibits stable physical behavior, low plasticity, and moderate porosity, with potential applications in civil construction or architecture, depending on the specific demands of each application (Figure 28).

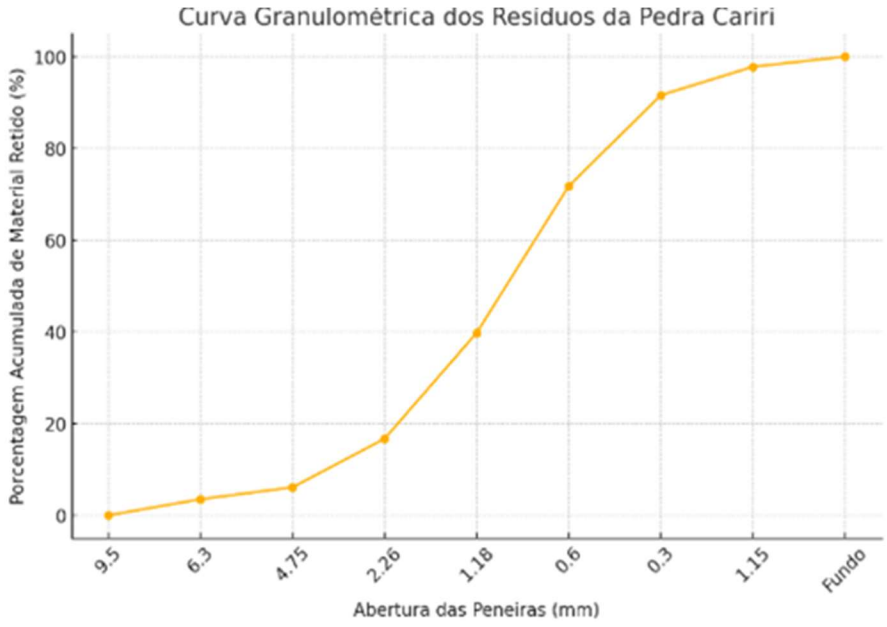
Initially, the material collected from the deposits was subjected to a comminution process, with the aim of reducing the particle size and facilitating subsequent processing steps. For this purpose, the material was

prepared within the particle size range between sieves with openings of 9.5 mm and 0.075 mm, as shown in Figure 28. This result is particularly relevant to produce aggregates from Cariri Stone, enabling its use as a partial or total replacement for natural aggregates in cementitious matrices, in addition to other construction and architectural applications.

The following shows the particle size distribution of the Cariri Stone waste, with Figure 29 referring to the yellow-colored waste and Figure 30 to the gray-colored waste. These materials correspond to the finely ground fraction, intended for applications in sintering processes and in the production of filler.

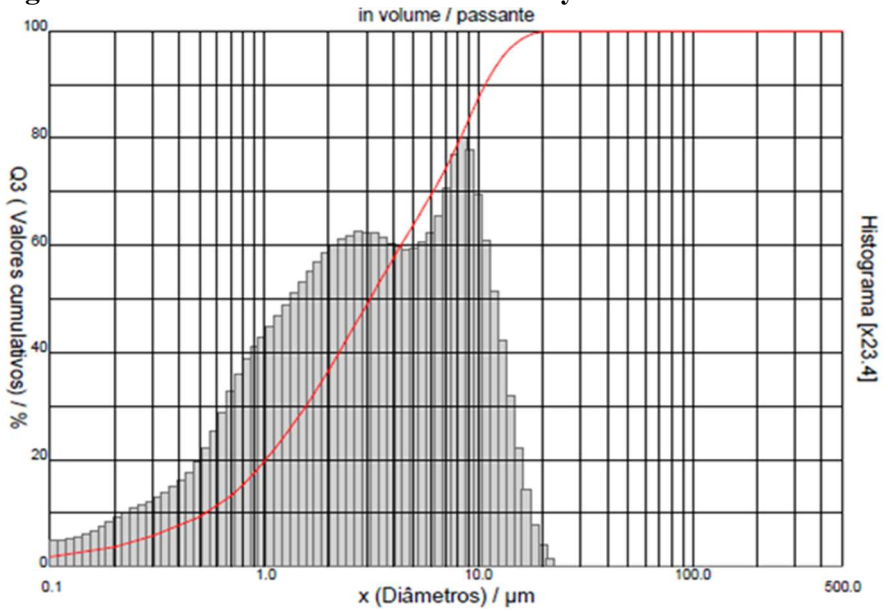
It is observed that the residues present a particle size distribution with a predominant concentration of particles in the range of approximately 1 to 9 µm, with 100% of the material having a particle size smaller than 30 µm. In terms of particle size, the average particle size determined was 5.1 µm for the yellow residue analyzed. Furthermore, these results are compatible with those reported by Menezes et al. (2010) for this parameter. Comparatively, the same particle size pattern was observed between the yellow and gray residues, which demonstrates a strong correlation between particle size distribution and material processing conditions, and not with the mineralogical or color nature of the residues.

Figure 28 - Particle size distribution curve of Cariri stone waste



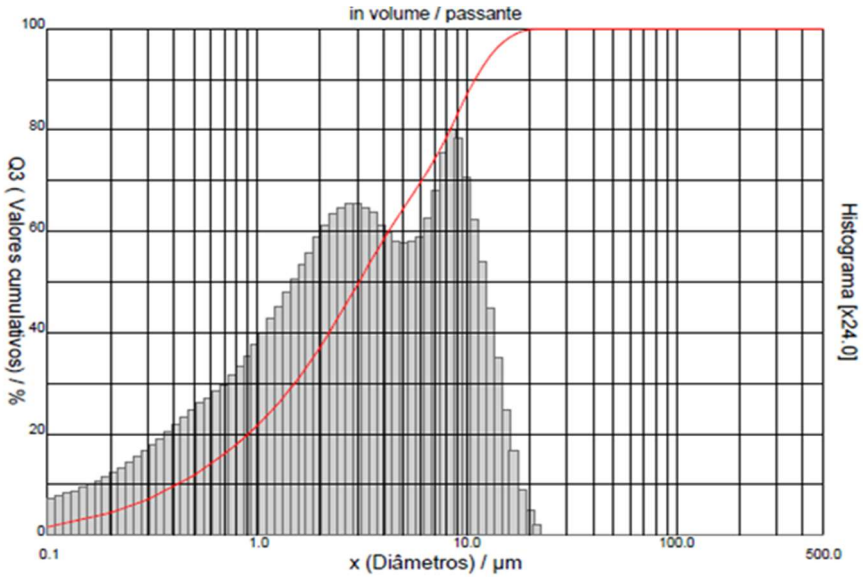
Source: prepared by the authors.

Figure 29 - Particle size distribution of the yellow Cariri Stone waste



Source: prepared by the authors.

Figure 30 - Particle size distribution of the gray Cariri Stone waste



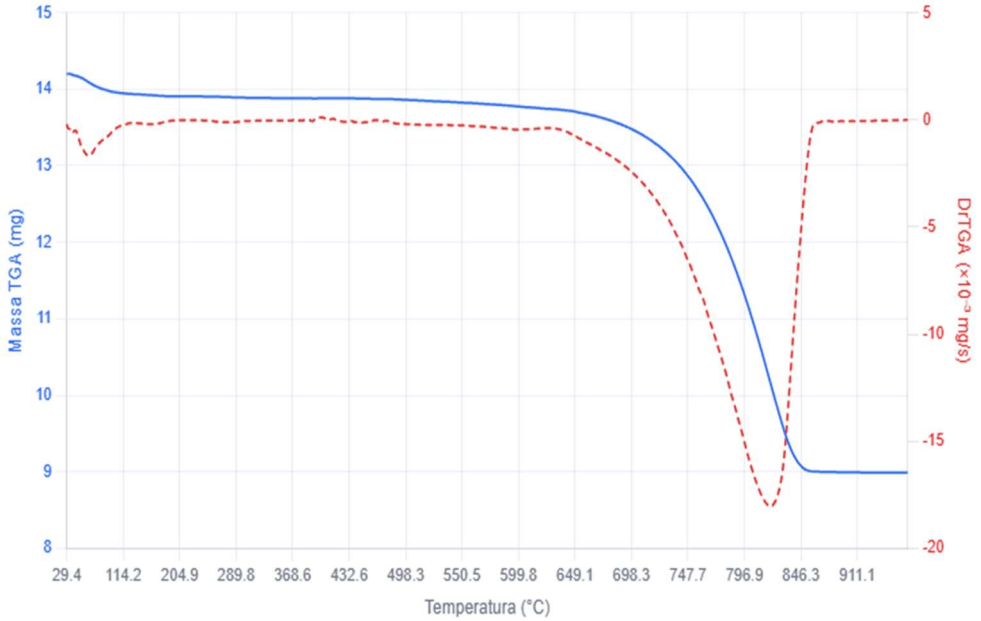
Source: prepared by the authors.

Thermal analyses, using Thermogravimetry (TG), aim to analyze the decomposition of phases or compounds present in the material when heated, by determining the residual mass of carbon. Figure 31 shows the thermogravimetric curve for the Cariri Stone residue.

A mass loss of approximately 45% is observed in the temperature range between 700 and 900 °C, with an endothermic peak around 945 °C, associated with the decomposition of calcium carbonate and the release of carbon dioxide, characteristic of the predominant mineralogical phase, calcite. These results are consistent

with the data obtained in the loss on ignition and X-ray diffraction tests.

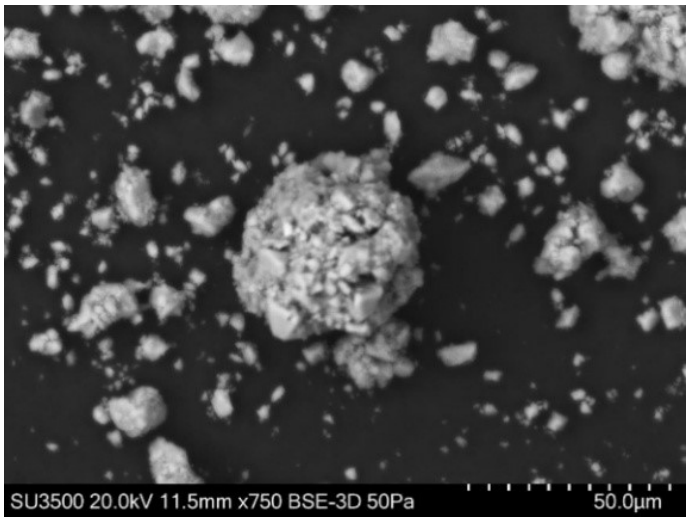
Figure 31 - Thermogravimetry (TG) of the Cariri Stone waste



Source: prepared by the authors.

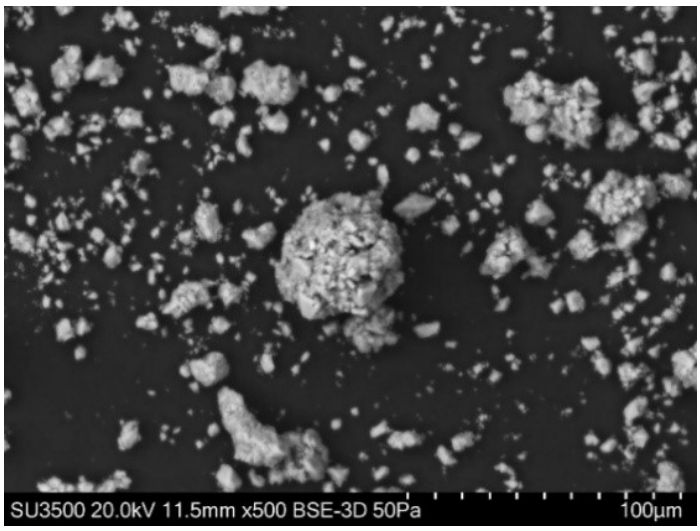
Under these conditions, a relevant parameter is identified for defining the calcination and/or sintering temperatures of Cariri Stone waste intended for the formulation of alternative cementitious binders. Furthermore, these results are fundamental for the analysis of carbon dioxide emissions associated with the alternative materials developed in this investigation. The micrographs shown in Figures 32 and 33 correspond to images of grains of Cariri Stone Residue (RPC) with yellow and gray coloration, respectively.

Figure 32 - Micrograph of the yellow Cariri Stone waste



Source: prepared by the authors.

Figure 33 - Micrograph of the gray Cariri Stone waste



Source: prepared by the authors.

Analysis of the micrographs reveals morphological similarities between both residues analyzed. It is observed that the materials present particles with slightly spherical shapes in the central images, associated with irregular surfaces, in addition to dispersed particles with varying sizes and shapes, predominantly lamellar morphology and dimensions smaller than the central particle, on the order of approximately 1 µm.

These results indicate a heterogeneous composition and a high degree of fineness of the material, suggesting a high specific surface area, potentially associated with greater porosity and water absorption capacity. Furthermore, a tendency towards friability is observed in the material, who's morphological and granulometric characteristics are directly related to the comminution and beneficiation process.

These aspects should be considered in the applications of the material, whether as a substitute or addition in cementitious matrices, or as a raw material for thermal processing steps, as in the case of the production of alternative cementitious binders.

6 FINAL CONSIDERATIONS

The results obtained in this research demonstrate that Cariri Stone waste possesses favorable technological characteristics for applications in civil construction and in the production of alternative cementitious materials. The predominance of calcite, associated with the high calcium oxide content and the low concentration of impurities, highlights the material's potential as a mineral source for calcination, sintering processes, and the formulation of alternative binders.

Physical analyses indicated low plasticity, fine particle size, and stable behavior, important characteristics for applications in mortars, concretes, ceramics, paving, and mineral filler materials.

Thermogravimetric tests confirmed the typical behavior of carbonate materials, while morphological analyses revealed particles with high fineness and large specific surface area, attributes relevant to the material's reactivity in cementitious matrices.

Beyond the technological aspects, the study highlights the urgent need for strategies focused on the sustainable management of waste generated by the Cariri Stone production chain. The high rate of waste observed during extraction and processing reinforces the importance of implementing circular economy policies, encouraging technological innovation, and strengthening the integration between universities, the productive sector, and public institutions.

It can be concluded, therefore, that the Cariri Stone waste has a high potential for reuse, and can contribute to reducing the environmental impacts associated with regional mining, as well as to the development of alternative materials with less environmental impact. However, further studies related to technical, economic and environmental feasibility on an industrial scale are still needed, aiming to consolidate sustainable applications and expand the use of this waste in the civil construction sector.

REFERENCES

ALENCAR-LINARD, Z. Ú. S.; LIMA, P. V. P. S.; SAEED-KHAN, A. Percepções dos impactos ambientais da indústria de cerâmica no município de Crato, estado do Ceará, Brasil.

ALVES, T. M. E.; SANTOS, A. M. M.; BRASILEIRO, M. I.; PINHEIRO, S. F. L.; PRADO, A. C. A. Produção de hidróxido de cálcio a partir de resíduo da Pedra Cariri. In: Congresso Brasileiro de Engenharia e Ciência dos Materiais, 22., 2016, Natal. Anais [...]. Natal: SBECIMAT, 2016.

ANUÁRIO DO CEARÁ. Economia do Cariri. Fortaleza: Fundação Demócrito Rocha/O Povo, 2025. Disponível em: Anuário do Ceará – Economia do Cariri. Acesso em: 20 maio 2026.

ASSINE, Mario Luis. Bacia do Araripe. Boletim de Geociências da Petrobras, Rio de Janeiro, v. 15, n. 2, p. 371-389, maio/nov. 2007.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 6457:2024: amostras de solo — preparação para ensaios de compactação e ensaios de caracterização. Rio de Janeiro: ABNT, 2024.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 6459:2025: solo — determinação do limite de liquidez. Rio de Janeiro: ABNT, 2025.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 7180:2025: solo — determinação do limite de plasticidade. Rio de Janeiro: ABNT, 2025.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 9775:2011: agregado miúdo — determinação do teor de umidade superficial por meio do frasco de Chapman — método de ensaio. Rio de Janeiro: ABNT, 2011.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 10007:2004: amostragem de resíduos sólidos. Rio de Janeiro: ABNT, 2004.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 14656:2023: cimento Portland e matérias-primas — análise química por espectrometria de raios X — métodos de ensaio. Rio de Janeiro: ABNT, 2023.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 16916:2021: agregado miúdo — determinação da densidade e da absorção de água. Rio de Janeiro: ABNT, 2021.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 16973:2021: agregados — determinação da distribuição granulométrica — método de ensaio. Rio de Janeiro: ABNT, 2021.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 17054:2022: agregados — determinação da massa específica, massa específica aparente e absorção de água de agregados graúdos. Rio de Janeiro: ABNT, 2022.

BACCI, D. C.; PIRANHA, J. M.; DEL LAMA, E. A.; BOGGIANI, P. C.; TEIXEIRA, W. Geoparque – Estratégia de Geoconservação e Projetos Educacionais. Geologia USP, Publicação Especial, v. 5, p. 7-15, 2009.

BARROSO, M. D. B.; MARINHO, R. M. M.; PEREIRA, F. M.; SANTOS, I. S.; MELO, P. S. Avaliação da incorporação de Pedra Cariri em massas de telhas cerâmicas. In: Congresso Brasileiro de Engenharia e Ciência dos Materiais, 22., 2016, Natal. Anais... Natal: 22º CBECiMat, 2016.

BATISTA, Deusa Kelly Ferreira Bezerra. Obtenção e caracterização de cimento aluminato de cálcio feito a partir do resíduo de Pedra Cariri e alumina comercial. 2023. Trabalho de Conclusão de Curso (Bacharelado em Engenharia de Materiais) – Universidade Federal do Cariri, Centro de Ciências e Tecnologia, Juazeiro do Norte, 2023.

BEZERRA, A. K. L.; SILVA, L. A.; ARAUJO, L. B. R.; CABRAL, A. E. B. Production and characterization of artificial stone for coating with laminated limestone waste in polymeric matrix. Ambiente Construído, Porto Alegre, v. 22, n. 4, p. 23-33, out./dez. 2022.

CARVALHO NETA, Maria de Lourdes. Geodiversidade, geoconservação e geovalorização no Geopark Mundial UNESCO Araripe e adjacências. 2019. 248 f. Tese (Doutorado em Geografia) – Programa de Pós-Graduação em Geografia, Universidade Federal de Pernambuco, Recife, 2019.

CORREIA, J. C. G.; VIDAL, F. W. H.; RIBEIRO, R. C. C. Caracterização Tecnológica dos Calcários do Cariri do Ceará. Rio de Janeiro: CETEM, 2008.

DIAS, Raíssa Barros; GONÇALVES, Lívia Kelly Bezerra; SILVA, Magno de Lima; FARIAS, Beatriz Maria Nunes de; PRADO, Ana Cândida de Almeida. Características do resíduo de Pedra Cariri visando seu uso como precursor de cimento refratário. In: Congresso Online de Engenharia de Materiais, 2021. Anais... 2021.

DILCHER, D. L.; BERNARDES-DE-OLIVEIRA, M. E.; PONS, D.; LOTT, T. A. Welwitschiaceae from the Lower Cretaceous of Northeastern Brazil. American Journal of Botany, v. 92, p. 1294-1310, 2005.

GALVÃO, J. S.; PITA, A. C.; MERCÊS, U. M.; MOURA, W. A.; LEITE, M. B. Estudo do uso de resíduo de serragem de Pedra Cariri na produção de misturas autoadensáveis. In: Encontro Nacional de Tecnologia do Ambiente Construído, 16., 2016, São Paulo. Anais... São Paulo: XVI ENTAC, 2016.

GONÇALVES, Jardel Pereira. Utilização de resíduo de corte de granito (RCG) como adição para produção de concreto. 2000. 132 f. Dissertação (Mestrado em Engenharia Civil) – Universidade Federal do Rio Grande do Sul, Programa de Pós-Graduação em Engenharia Civil, Porto Alegre, 2000.

GUIMARÃES, Cleidson Carneiro. Avaliação de blocos de argamassa produzidos com resíduo de serragem de Pedra Cariri. 2014. 95 f. Dissertação (Mestrado em Engenharia Civil e Ambiental) – Universidade Estadual de Feira de Santana, Programa de Pós-Graduação em Engenharia Civil e Ambiental, Feira de Santana, 2014.

HERZOG, A.; SALES, A.; HILLMER, G. O Geopark Araripe: uma pequena história da evolução da vida, das rochas e dos continentes. Fortaleza: Expressão Gráfica e Editora, 2008.

LIMA, F. F. et al. Geopark Araripe: histórias da terra, do meio ambiente e da cultura. Crato-CE, 2011.

LIVALTER, E. A. et al. Caracterização da mistura de argilas e rejeitos da Pedra Cariri: resultados preliminares. In: CONGRESSO BRASILEIRO DE CERÂMICA, 52., 2008, João Pessoa. Anais... João Pessoa: Associação Brasileira de Cerâmica, 2008.

MENDES FILHO, E. Uma avaliação do programa de apoio ao arranjo produtivo local da Pedra Cariri-Ceará. 2009. 120 f. Dissertação (Mestrado em Economia) – Universidade Federal do Ceará, Fortaleza, 2009.

MENEZES, Romualdo R. et al. Reciclagem do resíduo da serragem de calcário laminado para produção de blocos cerâmicos. REM: Revista Escola de Minas, Ouro Preto, v. 63, n. 4, p. 667-672, out./dez. 2010.

MOURA, W. A.; LEITE, M. B.; BASTOS, A. J. O. Avaliação do uso de resíduo de serragem de Pedra Cariri (RSPC) para produção de concretos convencionais. Ambiente Construído, v. 13, n. 1, p. 7-24, jan./mar. 2013.

NEIVA, L. S.; SILVA, G. R.; LIMA, P. H.; BARBOSA, F. N.; BRASILEIRO, M. I. Investigação das potencialidades de aplicação industrial para o resíduo da Pedra Cariri: uma reflexão sobre esta problemática ambiental e social. Caderno de Pesquisa, Ciência e Inovação, v. 1, n. 2, p. 102-109, 2018.

NUNES, Paula Hemília de Souza. Análise da saúde ambiental vinculada à extração da Pedra Cariri. 2015. 129 f. Dissertação (Mestrado em Desenvolvimento Regional Sustentável) – Universidade Federal do Cariri, Programa de Pós-Graduação em Desenvolvimento Regional Sustentável, Juazeiro do Norte, 2015.

OLIVEIRA, Diego Bandeira de. O uso do resíduo Pedra Cariri como material alternativo para aplicação em camadas granulares de pavimentos. 2016. 120 f. Dissertação (Mestrado em Engenharia de Transportes) – Universidade Federal do Ceará, Centro de Tecnologia, Departamento de Engenharia de Transportes, Fortaleza, 2016.

PEREIRA, Jaiane de Andrade. Aproveitamento de resíduo do beneficiamento da Pedra Cariri para a produção de concreto. 2019. Trabalho de Conclusão de Curso – Universidade Regional do Cariri, Juazeiro do Norte, 2019.

PONTE, F. C.; PONTE-FILHO, F. C. Estrutura geológica e evolução tectônica da Bacia do Araripe. Recife: DNPM, 1996.

SAMPAIO, João Alves; ALMEIDA, Salvador Luiz Matos de. Calcário. In: LUZ, Adão Benvindo da; LINS, Fernando Antonio Freitas (org.). Rochas e minerais industriais: usos e especificações. 2. ed. Rio de Janeiro: CETEM/MCT, 2008. p. 297-316.

SILVA, A. D. A.; FILHO, J. L. R.; SOUZA, J. C.; BARROS, M. L. D. S. C.; LIRA, B. B. Aproveitamento de rejeito de calcário do Cariri cearense na formulação de argamassa. Estudos Geológicos, v. 18, n. 1, p. 89, 2008.

SOUZA, A. R. S.; BEZERRA, F. C. O Soldadinho-do-Araripe (Antilophia bokermanni Coelho e Silva, 1988) como espécie bandeira no Cariri Cearense. In: Meio ambiente e sustentabilidade: conceitos e aplicações. 1. ed. 2022.

TAMMAM, Y. et al. Effect of Waste Filler Materials and Recycled Waste Aggregates on the Production of Geopolymer Composites. Arabian Journal for Science and Engineering, v. 48, n. 4, p. 4823–4840, 1 abr. 2023.

VIDAL, F. W. H.; CAMPOS, D. A. Explotando calcário e salvando fósseis na Chapada do Araripe. In: Congresso Brasileiro de Rochas Ornamentais, 3., 2007, Natal. Anais... Rio de Janeiro: CETEM/MCTI, 2008.

VIDAL, F. W. H.; FERNANDES, T. W. G.; PEQUENO, D. A. C. Inovação tecnológica para a valorização da Pedra Cariri, CE. In: Congresso Brasileiro de Rochas Ornamentais, 3., 2007, Natal. Anais... Rio de Janeiro: CETEM/MCTI, 2008. p. 299-306.

VIDAL, F. W. H.; PADILHA, M. W. M. A indústria extrativa da Pedra Cariri no Estado do Ceará: problemas x soluções. In: Simpósio de Rochas Ornamentais do Nordeste, 2003, Fortaleza. Anais... Rio de Janeiro: CETEM/SBG, 2003. p. 199-210.

VIDAL, F. W. H.; PADILHA, M. W. M.; OLIVEIRA, R. R. Aspectos do aproveitamento dos rejeitos da Pedra Cariri. In: Congresso Internacional de Rochas Ornamentais. Anais... Guarapari, ES, 2005.