

Characterization N’Gouri Diatomite Thermomechanical

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Abstract

N’Gouri diatomite, located in the Lake Chad Basin, is a silica-rich sedimentary material (>80%) characterized by high porosity and fine grain size. Three facies were studied (samples 44, D and M) to evaluate their potential in the production of local construction materials. Analyses show a low dry density (409 - 414 kg/m³), a stable specific gravity (671 - 679), a moderate water content (7.87% - 8.75%) and a high porosity (38.3% - 39.76%). Compressive strength varies according to the forming methods: $R_c \approx 2.7 - 2.9$ MPa for 44, $R_c \approx 2.0$ MPa for D and $R_c \approx 1.6 - 1.8$ MPa for M, while thermal conductivity remains low (0.15 - 0.20 W/m·K), confirming the insulating potential of the material. Comparison between manual and vibrocompaction methods shows a reduction in porosity and densification of the material, with varied effects on mechanical strength. These characteristics make N’Gouri diatomite an interesting candidate for the production of lightweight and insulating bricks adapted to local conditions.

Keywords

Diatomite, N’Gouri, Eco Materials, Physics, Thermomechanics

1. Introduction

Construction techniques using local materials are part of a millennia-old practice throughout the world, particularly in sub-Saharan Africa, where they offer both economical and accessible solutions for human housing [1]. This longevity is explained by the immediate availability of soils and the ease of their implementation. In the Lake Chad basin, geological analyses have revealed that the lake went through

four major phases of expansion between 39,000 BC and 300 BC, a period referred to as “Mega-Chad”. These episodes left behind thick layers of lake sediments and diatomaceous earth [2] [3], now considered a promising resource for local construction.

Diatomite, a sedimentary rock formed essentially of amorphous silica from fossilized diatoms, is distinguished by its lightness, high porosity and interesting thermal and mechanical properties [4] [5]. Its color, ranging from white to light gray, illustrates its purity and richness in silica. In the Chadian basin, particularly in the Bodélé depression, diatomite deposits are among the most important in the region [5] [6].

N’Gouri diatomite is particularly distinguished by its high silica content, generally above 80%, and by its low proportion of metal oxides (**Figure 1**). Compared to other global deposits, it has a fine and regular grain size, favoring its use in the production of lightweight and insulating materials. These characteristics position it as a material of choice for sustainable and economically accessible constructions, while offering thermal and mechanical performances adapted to local climates and needs.



Figure 1. Diatomite.

Construction techniques using local materials are part of a thousand-year-old tradition throughout the world and, more particularly, in sub-Saharan Africa. They offer solutions that are economical, accessible and adapted to local housing needs [1]. This sustainability is mainly based on the immediate availability of land and the simplicity of implementing these materials.

In the Lake Chad basin, geological studies have shown that the lake experienced four major expansion phases between 39,000 BC and 300 BC, a period known as “Mega-Chad.” These episodes resulted in the deposition of thick layers of lake sediments and diatom-rich earths [2] [3], now identified as a promising resource for local construction.

Diatomite is a sedimentary rock composed mainly of amorphous silica from fossilized diatoms. It is characterized by its lightness, high porosity as well as its interesting thermal and mechanical properties [4] [5]. Its color, ranging from white to light gray, reflects its purity and richness in silica. In the Chadian Basin, and more particularly in the Bodélé depression, diatomite deposits are among the largest in the region [5].

N’Gouri diatomite is distinguished by its exceptionally high silica content, generally above 80%, and its low concentration of metal oxides. Its fine and homogeneous particle size makes it particularly suitable for the manufacture of lightweight and insulating materials. These qualities make this material a preferred choice for sustainable, economical, and thermally and mechanically efficient constructions, meeting climatic constraints and the specific needs of local communities.

2. Material and Method

Presentation of the study area Sampling

Waye, in western Chad in the Lac province, is characterized by a Sahelian climate with high temperature variations, long dry seasons and annual rainfall of 200 to 300 mm. The clay-sandy soils and sparse vegetation favor the exploitation of earthy materials for the artisanal manufacture of bricks.

For this study, samples were collected from three local quarries in **Figure 2** (sites 44, D and M) at shallow depths (0.5 - 1.5 m) to avoid organic contamination and to collect representative material, according to NF P 94-040 (2020) and NF ISO 18400-102 (2017) standards. The samples were transported to the ENSTP laboratory in N’Djamena for detailed thermomechanical analyses.



Figure 2. Site 44, D and M respectively on the image.

Diatomite from these quarries is a siliceous material with high porosity, presenting interesting thermal and mechanical properties for the production of stabilized bricks. The analyses make it possible to evaluate the compressive strength, porosity, thermal conductivity and energy storage capacity, essential for optimizing formulations and comparing sites [4] [7]-[9]. This study thus aims to characterize the properties of N’Gouri diatomite and to propose avenues for its sustainable use in local construction. FRAINE, Youssouf, & SELADJI, Chakib. Algerian Diatomite: an Ecological Hygrothermal Insulation Material for Housing.

3. Diatomite Characteristic Method

3.1. Physical Characteristic Result of Diatomite

The properties of the diatomite collected in N'Gouri were carefully studied in the laboratory according to recognized standards, in order to ensure reliable and comparable results. The dry density and specific density were measured according to NF P 94-053 and NF P 94-054, providing information on the actual density and compactness of the material. The water content and porosity, determined according to NF P 94-050, provide information on the porous structure of the diatomite and its behavior with respect to humidity. The Atterberg limits (NF P 94-051) were used to characterize its plastic properties, while the granulometric and sedimentometric analysis (NF P 94-056/057) specified the particle size distribution, a key factor influencing cohesion and mechanical strength. Compression and tensile tests quantified the structural strength, and chemical analysis by X-ray fluorescence (XRF) identified the main oxides constituting the material, essential for understanding its thermomechanical behavior. Together, these investigations provide a comprehensive and comparative overview of samples 44, D and M, providing a solid scientific basis for their valorization in the manufacture of stabilized bricks.

The studied diatomites are distinguished by their low dry density (409 - 414 kg/m^3) as described in **Figure 3** and a stable specific gravity (671 - 679), typical characteristics of light and porous siliceous soils with a high amorphous silica content in **Figure 4** (>80%) [8] [10].

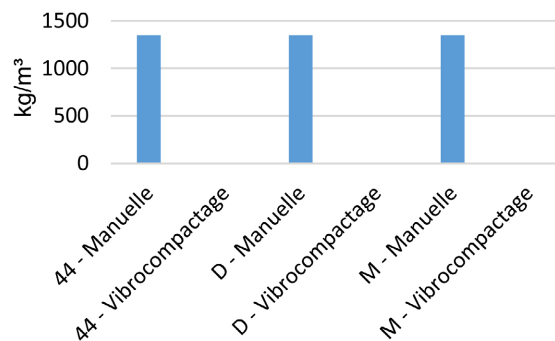


Figure 3. Density of different samples by different methods.

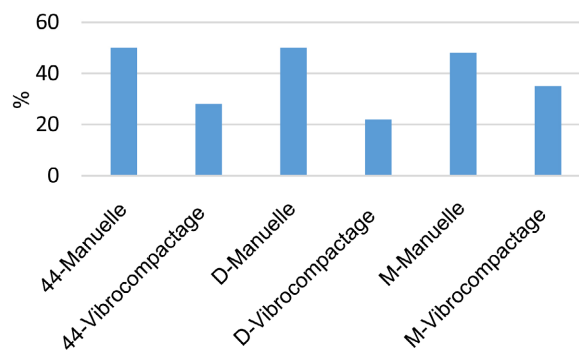


Figure 4. Porosity of different samples by different methods.

The study of N’Gouri diatomite highlights unique physical and mechanical properties that confirm its potential for use in civil engineering and materials. The moderate natural water content (7.87% - 8.75%), reflects a significant but unsaturated porosity, corroborated by porosity values between 38.3% and 39.76%. The void ratio follows this logic: sample 44 is distinguished by a more open structure and therefore more sensitive to water variations, while sample M presents a slight densification that makes it less vulnerable to changes in water content.

Plasticity tests reveal notable contrasts. The very high liquid limits (96% - 101%) associated with a variable plasticity index (11% - 18%) highlight the sensitivity of material 44, which is particularly plastic and reactive to humidity. Conversely, sample D is distinguished by greater stability, making it better suited to construction applications requiring more constant mechanical behavior. These results are consistent with the observations of Zhu [7], according to which diatomites, due to their high silica content and porous microstructure, exhibit significant variability depending on the facies studied.

In terms of granulometric analysis, sieveometric (NF P 94-056) and sedimentometric (NF P 94-057) analyses confirm the remarkable fineness of the diatomite: more than 80% of the particles pass the 80 micron sieve. This characteristic promotes high permeability, in agreement with the results reported by Abakar and Ali [11] [12]. However, differences between facies are noticeable. Sample D retains high proportions of fine particles, reflecting a homogeneous and stable texture. Sample 44, on the other hand, reveals a marked drop below 0.005 mm, indicating a coarser and less continuous fraction. As for sample M, it presents an intermediate distribution, but with a clear discontinuity around 0.08 mm (44.92% passing), which reflects a significant proportion of coarser grains.

Compared to the references of Bahar and Mesbah [13] [14], who describe diatomites as largely dominated by fine fractions (<0.063 mm) explaining their high porosity and their use as filters or insulators, the results of N’Gouri show a differentiated behavior. Sample 44 corresponds more to the expected profile of classical diatomites, while sample M, with its more heterogeneous grain size, stands out by a potentially weaker cohesion and a less predictable mechanical response.

Ultimately, the N’Gouri diatomite is not homogeneous: facies D and 44 appear finer and more regular, close to the behavior described in the literature, while sample M presents a coarser structure content in **Figure 5**. These differences probably reflect distinct sedimentation or diagenesis conditions, and they open up prospects for differentiated use depending on needs: light and porous materials for facies D and 44, and denser or structured materials for facies M.

3.2. Mineralogical Analysis

Diatomite is a light, porous and essentially siliceous material, known for its high adsorption capacity and its chemical inertness, since it does not contain carbonates and does not react with dilute hydrochloric acid.

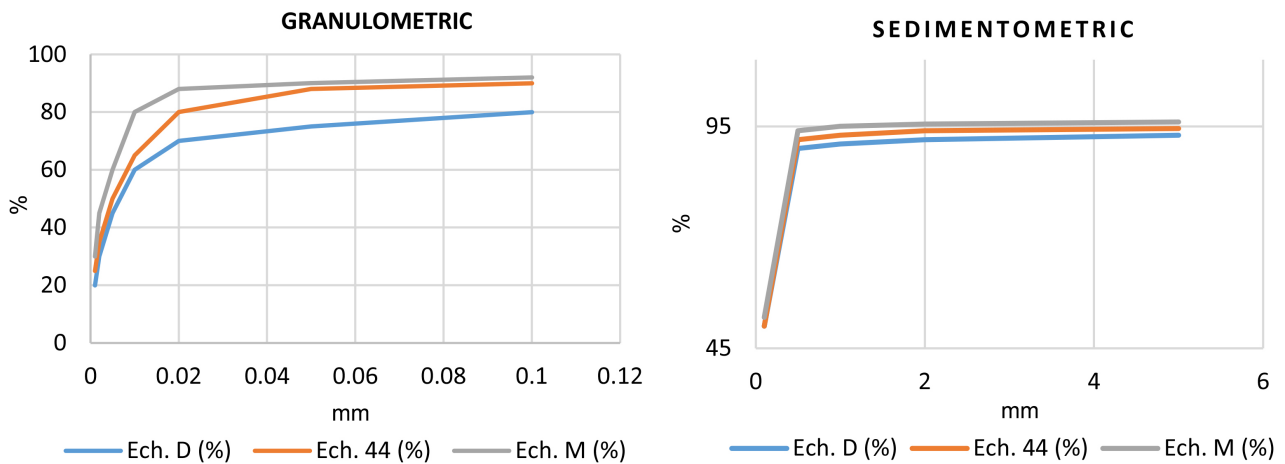


Figure 5. Particle size distribution curve. Granulometric curve (left) and sedimentometric curve (right).

Figure 6 describes the analyses carried out on the N’Gouri diatomite, reveals a composition dominated by silica ($\text{SiO}_2 = 83.17\%$), followed by alumina ($\text{Al}_2\text{O}_3 = 5.53\%$), lime ($\text{CaO} = 2.06\%$) and iron oxides ($\text{Fe}_2\text{O}_3 = 1.60\%$). Alkali and magnesia do not exceed 1%. This high silica content confirms the biogenic purity of the deposit and brings it closer to the diatomites of the Chadian basin described by Lemoalle and Ouedrago [15]-[17], while being slightly higher than the values of [18] (78% - 82%) and comparable to the results of Fraine and Lemoalle [4] (70% - 85%) [17].

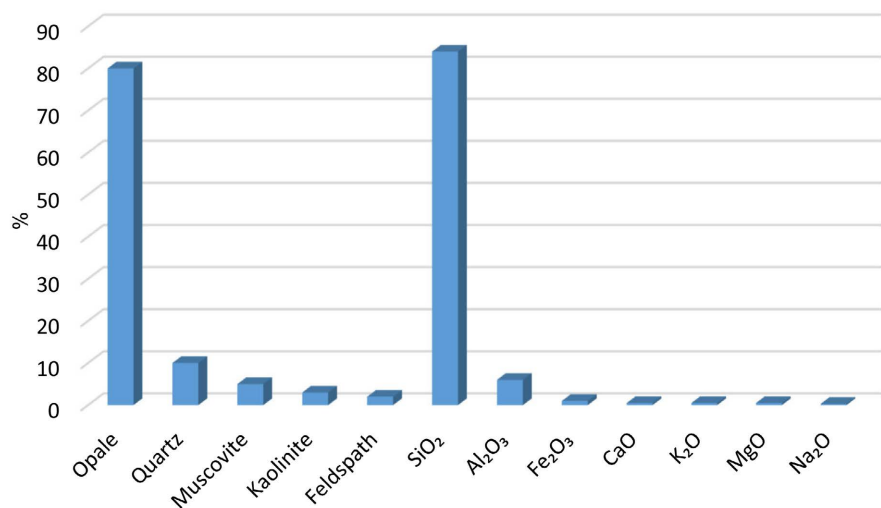


Figure 6. Chemical and mineralogical composition of diatomite.

The low proportion of alumina and iron reflects a limited clay content and gives the material a light color, advantageous for industrial applications (ceramics, mineral fillers). Similarly, the low content of carbonates and alkalis reinforces its thermal and chemical stability. Thus, N’Gouri diatomite has a chemical profile consistent with the large African deposits, but is distinguished by its purity and inertness, two major assets for its recovery.

The N’Gouri diatomite is characterized by a richness in silica (83.17%), confirming its belonging to high purity diatomites. However, this content remains slightly lower than the values reported in the international literature, which frequently exceed 85% - 90% [19]. The analysis also reveals significant contents of alumina (5.53%) and iron oxides (1.60%), contrasting with some reference diatomites, often poorer in Al_2O_3 (<3%) and Fe_2O_3 (<1%).

Regionally, diatomites from the Congo Basin, for example, have SiO_2 contents of up to 88% depending on the source. Compared to these data, the N’Gouri diatomite falls within an intermediate range, reflecting both good siliceous purity and a slight influence of secondary oxides [20]. The presence of CaO probably reflects a local geological contribution, rarely mentioned in North African diatomites with a predominantly siliceous content.

These geochemical differences suggest that the N’Gouri diatomite has a specific profile, combining a high silica content and a measured proportion of secondary oxides. This composition gives it original properties, particularly in terms of porosity, thermal stability and potential in construction materials. Thus, even if it does not fully compete with the purest deposits recorded, it offers significant scientific and industrial interest, justifying an in-depth study of its performance and applications in a Sahelian context.

3.3. Mechanical Characterization

N’Gouri diatomite is distinguished by mechanical properties closely linked to its porous structure and its high amorphous silica content (>80%). The mechanical analysis carried out (Figure 7) reveals a relatively modest compressive strength, with values of the order of a few MPa, which corresponds to the behavior usually observed for natural diatomites.

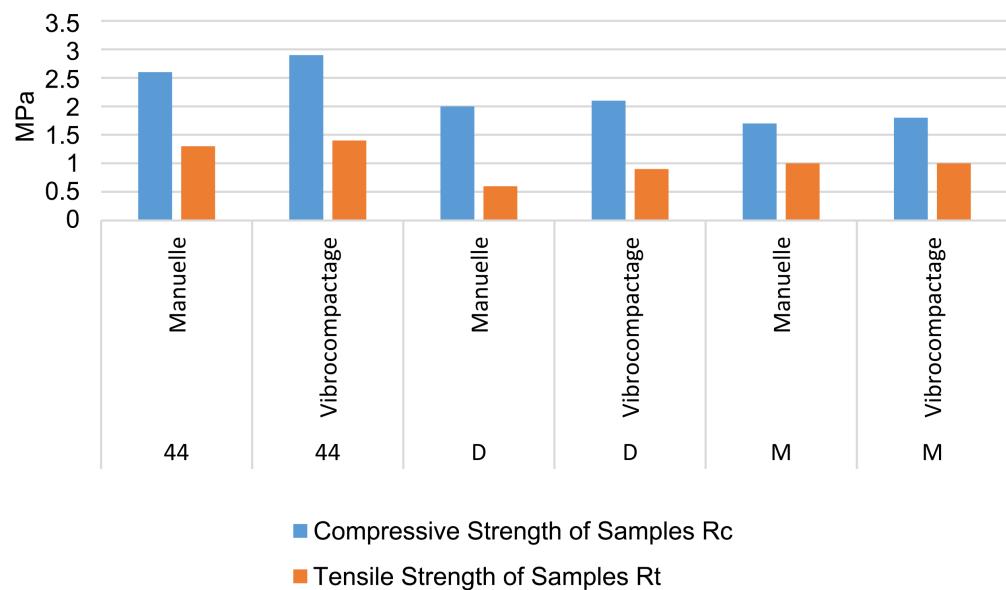


Figure 7. Mechanical characterization.

In comparison, the work of Merdai and Morin [6] [16] [20] and [2] [4] [18] reports compressive strengths generally varying between 1 and 5 MPa depending on the geological origin and the processing conditions of the diatomites. The results obtained for N’Gouri are therefore within this range, confirming the consistency of its performance with those described in the literature. However, its low dry density (approximately 0.40 g/cm³) and its marked porosity give this material a singularity that differentiates it from the more compact diatomites studied in Europe or Asia.

This comparison highlights a double observation: on the one hand, N’Gouri diatomite shares the general characteristics of diatomites exploited in the world; on the other hand, its light texture and its specific resistance offer interesting prospects for applications requiring both mechanical performance and insulating properties, particularly in the field of local construction materials.

3.4. Thermal Characterization

N’Gouri diatomite is a sedimentary material of biological origin, characterized by a porous structure and low bulk density. Chemical analyses confirm that its composition is dominated by silica (SiO₂ > 80%), accompanied by small proportions of Al₂O₃, Fe₂O₃, CaO and MgO, reflecting local geological conditions and sedimentation processes. **Figure 8** illustrates this composition and the grain size of the material, highlighting a relatively fine and homogeneous distribution of particles.

Thermal properties of the samples, conductivity (W/m·K)

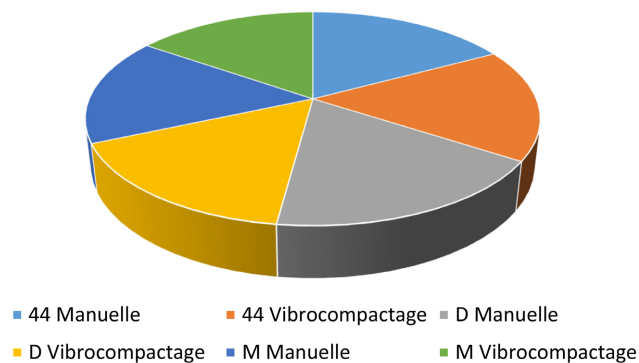


Figure 8. Interaction curve between thermal properties.

Thermal point of view, measurements carried out on the N’Gouri diatomite reveal a relatively low thermal conductivity, confirming its potential role as a natural insulator. For example, the measured conductivity is around 0.15 - 0.18 W/m·K, which is slightly lower than the values reported for similar type diatomites in the literature [8] [16] [20], where conductivities typically vary between 0.18 and 0.22 W/m·K. This difference can be explained by the finer grain size and slightly higher porosity of the N’Gouri sample, which increase the insulating effect by the presence of air trapped in the pores.

Thus, compared to diatomites studied in other regions, N’Gouri diatomite combines high silica purity with optimized thermal performance, making it particularly suitable for applications requiring both lightness, thermal insulation and compaction potential in brick or composite formulations. These unique characteristics position it as a promising material for the development of sustainable solutions in construction and composite materials.

3.5. Thermomechanical Behavior

The results show a strong interaction between mechanical and thermal properties.

For sample 44, the compressive strength ($R_c \approx 2.7 - 2.9$ MPa) is relatively high, while the diffusivity remains moderate ($\sim 0.16 - 0.20$ m²/s). The literature reports that diatomites, due to their high silica content (>80%), have low conductivity ($\sim 0.1 - 0.2$ W/m·K) and limited mechanical strength. Here, the measured conductivity ($\sim 0.19 - 0.20$ W/m·K) is well within this range, confirming the consistency of the results.

For sample D, the higher porosity (up to $\sim 50\%$) results in lower strength ($R_c \approx 2.0$ MPa in manual, 2.0 MPa in vibrocompaction). The literature [16] [21] reports that porosity directly controls the conductivity and mechanical strength of diatomites, with a decrease in thermal conductivity and mechanical embrittlement when porosity exceeds 60%. Our values ($R_c < 2.1$ MPa, porosity $\sim 50\%$) confirm this trend.

For sample M, the results are intermediate: $R_c \approx 1.6 - 1.8$ MPa and $R_t \approx 0.97$ MPa, with a porosity of $\sim 50\%$. The conductivity (0.18 - 0.19 W/m·K) is slightly lower than that of sample 44, corresponding to a slightly lower density. These results corroborate the work of Alvarado [22] on diatomites used as thermal insulators.

Vibrocompaction reduces porosity (up to 23% for D, compared to 50% in manual), which increases density but does not systematically improve mechanical resistance - a phenomenon also reported by [8] [21], where densification increases conductivity without necessarily strengthening cohesion.

Our conductivity (0.16 - 0.20 W/m·K) and porosity (28% - 50%) values are very close to the classic ranges cited in international studies (0.1 - 0.3 W/m·K and porosity 30% - 70%), which validates the experimental quality and places the N’Gouri diatomites within world standards (Figure 9).

4. Results and Discussion

4.1. Physical Properties

The study reveals that sample 44 has a more open structure, with a porosity of 39.76% and a water content of 8.75%, while M is slightly denser, with a porosity of 38.3% and a water content of 7.87%. Sample D falls in between, with a porosity close to 39%. These variations reflect differences in natural compaction and sedimentation. The fine and homogeneous grain size of D and 44 favors cohesion and mechanical stability, while M, with a higher proportion of coarse grains ($\sim 44.92\% > 0.08$ mm), may have less cohesion.

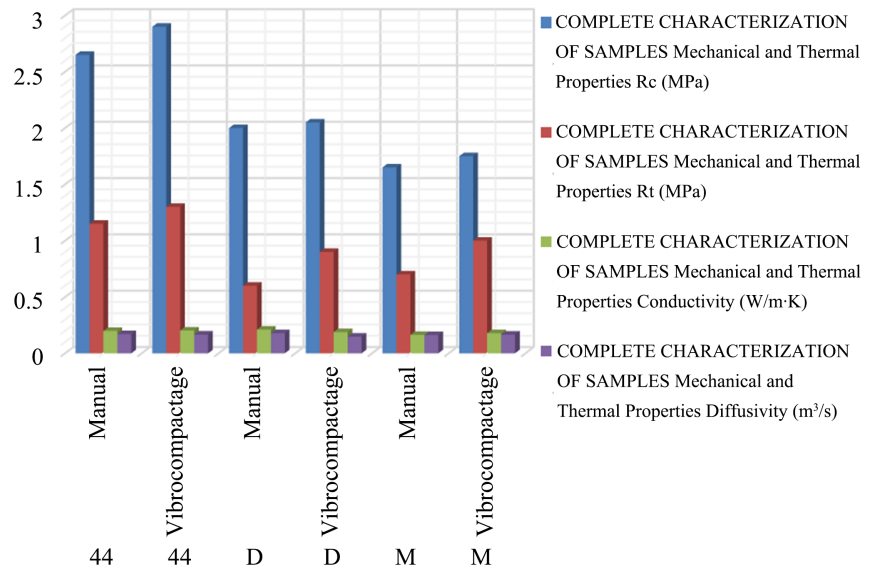


Figure 9. Interaction curve between mechanical and thermal properties.

4.2. Mechanical Properties

Compressive strength follows the logic of porosity and density: 44, with slightly higher density and better compactness, reaches $R_c \approx 2.7 - 2.9$ MPa, compared to $R_c \approx 2.0$ MPa for D and $R_c \approx 1.6 - 1.8$ MPa for M. Vibrocompaction significantly reduces porosity (up to 23% for D), increasing density but not always proportionally improving strength, confirming that densification favors thermal conductivity more than mechanical cohesion.

4.3. Thermal Properties

Thermal conductivity varies little between samples (0.15 - 0.20 W/m·K), despite differences in porosity and density, indicating that air within the pores plays a dominant role in insulation. Thermal diffusivity remains moderate ($\sim 0.16 - 0.20$ m²/s for 44), which, coupled with the low density, gives diatomite excellent insulating potential.

4.4. Thermomechanical Interaction

A strong interaction is observed: a reduction in porosity via vibrocompaction increases density and thermal conductivity, but mechanical strength does not always evolve proportionally. Sample 44, the most dense and compact, combines the best strength ($R_c \approx 2.7 - 2.9$ MPa) with a relatively low thermal conductivity (0.19 - 0.20 W/m·K), illustrating an optimal compromise between insulation and mechanical performance. D and M, more porous, offer slightly lower conductivity but lower strength, indicating a possible adaptation depending on the intended use (lightweight bricks vs. load-bearing materials).

5. Conclusion and Perspectives

N’Gouri diatomite has favorable physical, mechanical, and thermal characteristics

for use in local construction. Sample 44 is distinguished by its higher density and strength, D by its intermediate stability, and M by its coarser grain size and lower strength. Processing methods significantly influence porosity and, consequently, density and thermal conductivity, while mechanical strength remains relatively moderate. The combination of lightness, thermal insulation, and acceptable strength makes N’Gouri diatomite a promising material for the manufacture of lightweight, insulating bricks suitable for Sahelian climatic conditions.

6. Recommendation

- Choice of facies:** favor samples 44 and D for the production of bricks intended for light and insulating constructions.
- Compaction method:** Use vibrocompaction to reduce porosity and increase density, while monitoring the impact on mechanical strength.
- Hybrid formulations:** combine the M and D or 44 faces to obtain a compromise between density, resistance and thermal insulation depending on the use.
- Local applications:** favor diatomite in constructions requiring good thermal comfort, such as homes and non-load-bearing infrastructures, while taking into account its limited mechanical resistance.
- Additional studies:** further optimization of stabilized brick formulations by integrating natural binders or additives to improve mechanical resistance while retaining insulating properties.

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Authors Contributions

All authors having equal contribution for this article.

Conflicts of Interest

No conflicts of interest to the best of our knowledge.

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