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Valorization of Local Resources for Sealing of Mining Facilities: Characterization of A Geosynthetic Clay Liner Using Clay and Kenaf Fibers from Burkina Faso

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ABSTRACT
Since the early 2000s, Burkina Faso has experienced significant growth in the mining industry, generating large quantities of waste that require strict management in dedicated facilities. To limit pollutant migration in these mining sites, imported manufactured materials such as Geosynthetic Clay Liners (GCLs) and geomembranes are commonly used for sealing purposes. This study explores the use of local resources to develop an alternative clay-based geosynthetic. For this purpose, a woven geotextile made from kenaf fibers from the locality of Nérékorosso was bonded to a local clay collected in the locality of Toula. The properties of this clay were evaluated through several parameters: plasticity index, bulk density, free swell index, cation exchange capacity, specific surface area, and permeability coefficient. This study reveals that the clay from Toula shows a swell index of 4 ml/2 g, a permeability coefficient of 2.86×10^{-10} m/s, a cation exchange capacity (CEC) of 12.72 meq/100 g, and a specific surface area of 314.85 cm^2/g. The resulting geosynthetic exhibits tensile strengths of 2.03 kN/m in the machine direction and 14.46 kN/m in the cross direction. Although the current properties do not yet meet the regulatory standards for Geosynthetic Clay Liners (GCLs), amending the local clay with bentonite could enhance its sealing performance and offer a more accessible and sustainable solution for mining infrastructure in Burkina Faso.

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Introduction

Faced with the challenges of sustainable development, the mining sector is emerging as an active contributor to sustainable solutions. It is the country's leading economic sector, accounting for 20% of government revenue and 70% of exports. With a dozen gold mines in production, waste management is a major challenge for environmental protection. Mining waste, particularly cyanide and mercury, is a source of pollution for surface and groundwater in particular, exposing current and future generations to water and health problems. In recent years, the mining industry in Burkina Faso has undergone considerable development, resulting in a significant production of mining waste. Indeed, the extraction of gold by amalgamation with mercury generates waste containing 32500 kg of mercury (Hg) per year, which can be distributed in the air, water and soil [1]. Joël [2] reveals that, in general, 0.3 to 0.5 g of cyanide are needed to extract one ton of ore, but that, in practice, mining industries use 300 to 2000 g of cyanide per ton of ore for more efficient extraction. The use of chemicals such as cyanide and mercury at mining sites, particularly in amalgamation ponds at artisanal and small-scale mining sites (gold panning), poses a risk of contamination of groundwater resources. Indeed, recent studies reveal a worrying level of mercury contamination of groundwater from artisanal and small-scale gold panning. In Lombok (Indonesia) and Migori County (Kenya), high concentrations have been detected near community wells due to the uncontrolled discharge of mining waste [3-4]. In Migori, mercury levels exceed potability standards in the dry season, directly exposing local populations [4]. Also in Indonesia, a study in the Sukabumi regency revealed widespread contamination of the environment, including groundwater [5]. In particular, it was reported that cyanide waste from processing tanks flows directly into small rivers, raising concerns about environmental impacts [6]. This work underlines the urgent need for more rigorous management of the environmental impacts of mining activities.

To address these pollution issues, an impermeable material is installed at the bottom of mining facilities to limit the loss of pollutants by infiltration into the subsoil. Thus, as part of a sustainable development approach, mining industries in Burkina Faso—like those in other countries—are turning to the use of geosynthetics (geomembranes and GCLs) to improve waste management, limit pollutant infiltration and enhance environmental protection in their operations. A major advantage of GCLs over geomembranes is their ability to self-seal in the event of perforation.

Although used at certain mining sites in Burkina Faso, these GCLs are in most cases imported, at high cost, notably due to a lack of local production units and the absence of bentonite on a national scale. This state of importation could be a determining factor in the availability or

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accessibility of such products. At a GeoAfrica conference held in Morocco in 2017, it emerged that on the African continent, geosynthetics are most widely used in South Africa, Ghana and the Maghreb countries [7].

GCLs are roll-shaped manufactured materials consisting of a layer of bentonite (with low permeability [$k \leq 5x10^{-11}$ m/s] and high Free Swell Index [FSI ≥ 10 ml/2g]) held between two layers of geotextiles to provide the sealing function [8-9]. Their sealing function relies on the bentonite they contain. Geotextiles, on the other hand, act as containers and provide protection. To be fully sealed, clays need to be both highly impermeable and highly swellable. When used in contact with polluting solutions, GCLs must have a very high cation exchange capacity, not only to ensure the sealing function, but also to limit the risk of pollution downstream of the GCL.

Given the absence of bentonite in Burkina Faso, the present work explores the possibility of studying a local clay assembled with a biosourced geotextile for the manufacture of a geosynthetic. The local clay comes from Toula, in the south-central region of Burkina Faso. It was chosen because it belongs to the Vertisol family of swelling clay soils, similar to bentonite but with iron intrusion in the crystalline network and a cation exchange capacity (CEC) greater than 30 meq/100 g [10]. The geotextile uses kenaf fibers from the Boucle du Mouhoun region in northwest Burkina Faso. Kenaf fibers were chosen for the significant advantages they offer over synthetic fibers in terms of lightness, environmental friendliness and low cost [11].

This study focuses on three areas: the physical and hydraulic characterization of a local clay; the manufacture and characterization of a geotextile and a geosynthetic assembled from natural fibers and clay; and the analysis of the performance of the geosynthetic obtained with a view to its application in mine waste management.

Experimental

Characterization of the geological context of the Toula zone

The Toula clays are located in south-central Burkina Faso and cover around 5 km^2. In this locality, the relief encountered are mainly footslope of the glacis, mid-slope glacis, upper slope glacis, depression and alluvial plain (Figure 1).

The geological context of the sampling area is characterized by a scarcity of outcrops, found only in the arms and beds of rivers. The study area is covered by alluvial and colluvial deposits. Sporadic outcrops of acidic volcanic rocks, including rhyolites, sometimes metamorphosed and deformed in places. With the aid of boreholes to characterize the clays, the rock evolves into generally brown schists at depths of around one meter and sometimes more. Most of the clay derived from the weathering of this rock is found in the form of clay deposits along the banks of watercourses.

Physical and hydraulic characterization of the clay

This section aims to characterize the physical parameters (particle size, plasticity index, bulk density, free swelling index, cation exchange capacity, specific surface area, etc.) and the hydraulic parameter (permeability coefficient). Knowledge of these properties is important when comparing them with bentonite reference values.

Physical characterization

The determination of each parameter followed an experimental procedure defined by a standard. For example:

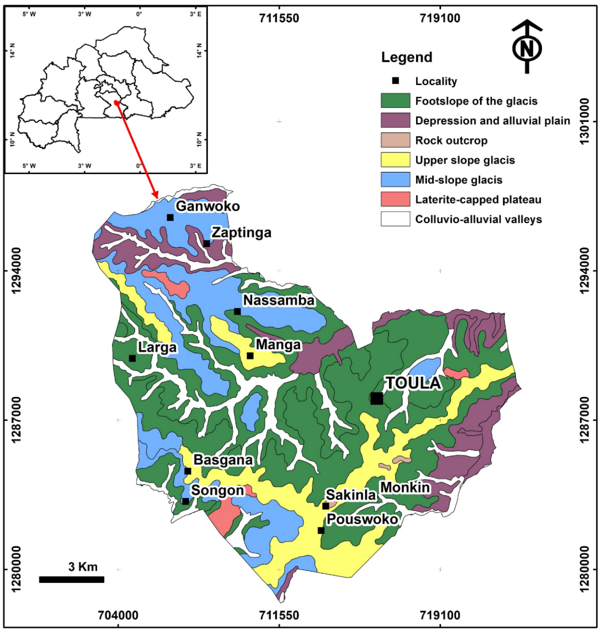


Figure 1: Relief map of the locality of Toula

- Granulometry was determined simultaneously by sieve analysis and sedimentometry in accordance with standards NF P 94-056 and NF P 94-057 ;
- The plasticity index (PI) was determined in accordance with standard NF P 94-051 ;
- The free swelling index was determined in accordance with standard XP P 84-703 ;
- CEC and specific surface area were obtained by the procedure described by Kafi [12], from formulas dependent on the methylene blue value.

Hydraulic characterization

The permeability coefficient is a key indicator of the effectiveness of GCLs in fulfilling their sealing function. This parameter indicates the rate at which water can permeate the clay under study. The permeability coefficient was determined using an API filter press test. This method is well documented and detailed by authors such as Barast et al [13], Yonli et al [14], Toguyeni and Yonli et al [15], Paumier et al [16], etc. It is used to determine the permeability of a clay in a very short test time, characteristic of the ease with which water can flow through a clay sample subjected to 7 bar air pressure.

For filtration, 300 ml of the mixture, after 24 hours' homogenization, is introduced into the filter cell. The cell is then firmly attached to the frame. Installation of a compressed air inlet pipe upstream and a container for collecting the filtrate downstream makes the equipment operational. By applying a controlled pressure, the phases are separated: the liquid passes through the filter, while the solid particles are trapped. During this stage, the volume of filtrate obtained is recorded as a function of time, and the operation is limited to one hour. After this period, the cell is dismantled, and a compact solid, called cake, is gently collected from the filter surface. This cake results from the accumulation of solid particles contained in the initial mixture. The test is run for one hour to ensure that the solid deposit (cake) is saturated. However, if material retention is insufficient, the experiment is stopped as soon as the first air bubbles appear. The thickness of the cake can then be measured to estimate the soil's permeability coefficient.

Assuming the existence of a Newtonian fluid flowing through a medium where Darcy's law is applicable, Darcy's law can be written as :

$$V^2 = \frac{2KS^2P}{\mu b}t \quad (1)$$

where V is the cumulative volume of filtrate, K is the intrinsic permeability of the soil, S is the sample surface area, P is the pressure, μ is the viscosity of the filtered fluid and

$$b = cS/V \quad (2)$$

the specific volume of cake deposited per unit volume, c the thickness of the cake. Intrinsic permeability is related to permeability coefficient as follows:

$$K = \frac{k\mu}{\rho g} \quad (3)$$

where ρ is the density of the liquid and g is the acceleration of gravity.

To determine the permeability coefficient (k), the curve V = f($t^{0.5}$) must be plotted and a linear fit of this this curve must be represented. The slope of this line is used to determine k.

To minimize uncertainties associated with the cake thickness, multiple measurements are taken along its perimeter, and the mean thickness is then determined.

Manufacturing and characterization of the geotextile and the Geosynthetic Clay Liner (GCL)

Manufacturing procedure and characterization of kenaf fiber geotextile

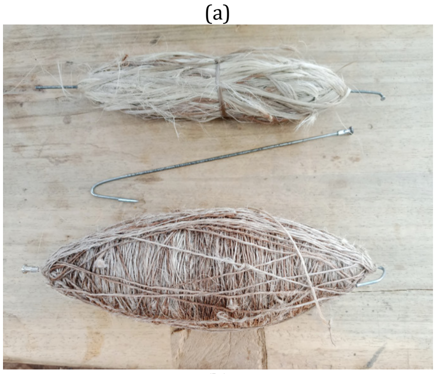
Kenaf is a plant cultivated throughout Burkina Faso for a variety of uses (use of the seeds, rope-making, consumption of the leaves, mask-making, etc.). The kenaf fibers used in this study come from Nérékorosso, a locality located in the Boucle du Mouhoun region. This locality was chosen as the sampling area, given its large-scale production of kenaf fibers for mask-making and cultural ceremonies.

Kenaf geotextiles (Figure 2.a) are manufactured by converting the fibers into yarns, followed by weaving. During threading, the fibers, divided into shreds and connected to a rod, are twisted at around 12 turns on themselves. The twist applied gives the fiber a stronger, more resistant consistency. The 12 turns were fixed in view of the fact that the yarns broke beyond 15 turns.

The wires (Figure 2.b) thus obtained are carried over a manual device to weave the geotextile. The resulting geotextile (Figure 2.c) has a quasi-closed structure, with minimal porosity, to ensure effective retention of clay particles while allowing drainage of liquid effluents.

The geotextile is then characterized to determine its mass per unit area and thickness. Its mass per unit area is determined according to the experimental protocol described in standard NF EN ISO9864 (October 2005), and its thickness using a micrometer. The mass per unit area is the average of the masses of 10 square geotextile specimens of identical dimensions (10 cm x 10 cm).

(a)



(b)

(c)

Figure 2: Kenaf fibers at different stages of the geotextile manufacturing process: a. Kenaf fibers; b. Kenaf wires; c. Geotextile

Procedure for Assembling and Characterizing the Geosynthetic Clay Liner (GCL)

The assembly is carried out taking into account the granular fraction of the clay and the targeted thickness of the geosynthetic. Recent studies have shown that the Naue Group industry assembles bentonite geosynthetics with clays whose grain size is less than or equal to 200 micrometers. For this reason, the 0/160 µm granular fraction was chosen (based on the granulometric results obtained from the clay) and the thickness of the geosynthetic was set to be blended at 1 cm. The Geosynthetic Clay Liner (Figure 3) is bonded using the following protocol: two geotextiles of known surface area are cut, depending on the desired sample size. The mass of clay per unit area of geotextile is then weighed. The clay is moistened with 50% water to improve its workability. Next, the face of the lower geotextile is sprayed with a water-soluble adhesive, and the entire clay layer is evenly applied to it. The face of the second geotextile is also sprayed with adhesive and covered with a layer of clay. Finally, a 2.5 kg mass is applied for 10 minutes to ensure proper bonding, which is valid for a 10 cm^2 geosynthetic specimen.

Figure 3: Assembled Geosynthetic Clay Liner

The geosynthetic was characterized by determining parameters such as thickness, mass per unit area and tensile strength. Thickness and mass per unit area were determined by micrometer measurement. The mass per unit area was determined by weighing on a precision balance, relating the mass obtained to the surface area of the geosynthetic.

(a) (b)

Figure 4: Tensile testing of a geosynthetic using traction device: (a) Tensile tester; (b) Geosynthetic under traction

Strength, meanwhile, was determined by approaching the ISO 10319 standard of May 2015. The test consists of pulling a test specimen held over its entire length or width between two jaws of a tensile testing machine (operating at constant speed) until it breaks (Figure 4). Unlike ISO 10319, which calls for tensile tests to be carried out on specimens of 200 mm (± 1mm) nominal width by 100 mm (± 1mm) nominal length (distance to be observed between the jaws), specimens of 40 mm nominal width by 100 mm nominal length were used. The test is used to determine the geosynthetic's tensile strength, characterized by the maximum force supported and the elongation at break.

Results and Discussion

Clay properties

Table 1 presents the results obtained from the physical and hydraulic characterization of Toula clay. The values for cation exchange capacity (CEC), specific surface area (Ssp) and plasticity index (PI) indicate that the clay sample studied comes from a highly plastic illite soil.

The clay used in geosynthetics is commonly known as "bentonite". It generally comes from a soil whose characteristics are very similar to those of smectite. The CEC and specific surface area of bentonite can vary from 80 to 150 meq/100g and 700 to 840 m^2/g respectively [17-18]. Its plasticity index varies between 70 and 100 when it is calcic and between 300 and 600 when it is sodic [19].

The results obtained during the particle size analysis test enabled us to observe the different classes of grains that make up the clay sample and thus classify it as fine clayey sand. Hydraulic characterization resulted in a permeability coefficient of 2.86 x 10^{-10} m/s. These results are shown in Table 2.

Figure 5.a shows the evolution of the cumulative volume of infiltrated water in the clay suspension. After one hour (1 h), we record a cumulative infiltration of 120 ml. We note that at the start of the test, the graphs follow a curvilinear trend, which can be explained by the gradual establishment of the steady state as the cake forms. The curve then becomes linear. This trend is explained by the formation of an agglomerate of solid particles (called cake) at the bottom of the cell and the establishment of a steady state. The graph in figure 5.b clearly shows the linearity between cumulative filtered volume and the square root of time, in accordance with Darcy's law. The linear adjustment carried out allows us to see the quality of the results from the R^2 value, which is approximately equal to 1. The permeability coefficient or hydraulic conductivity k is a function of the slope of the linear adjustment line.

The value of the permeability coefficient obtained, between 10^{-12} and 10^{-9} m/s and Table 2 of the particle size analysis results, confirms the majority content of the clay fraction in the sample.

Properties of the geotextile and the Geosynthetic Clay Liner

Table 3 shows the characteristics of a woven geotextile with a mass of approximately 1106.9 g/m^2 and an average thickness of 2.13 mm. The clay geosynthetic manufactured is composed of 7 kg of clay/m^2 of geotextile and has a mass per unit area of 8.06 kg/m^2 with a thickness of 9.06 mm, as presented in Table 4. These results can be seen on the graphs presented in Figure 6.

The tensile strength of the geosynthetic is 2.03 kN/m in the production direction (longitudinal direction) and 14.46 kN/m in the cross direction (transversal direction), with respective strains at break of 9.41% and 41.14%. In graph a of Figure 6, a first break is observed at 11 kN/m; this may be attributed to the sudden rupture of certain geosynthetic threads during the test, which can be explained by the heterogeneity in the diameter of the threads composing the geotextiles. The difference in resistance observed in the two directions of the geosynthetic can be explained by the difference in density of the main threads, a function of their spacing in each direction. The geosynthetic has good tensile strength in the cross direction, as its value is higher than the reference value (8 kN/m) for the manufacture of geosynthetics.

The strength of the produced geosynthetic can be improved by repeating the spinning operation and weaving the geotextile with new spinning and weaving characteristics that vary the twisting force (number of turns) and the spacing of the longitudinal rows during weaving.

Table 1: Results of the physical parameters of the characterized clay

Water content	Organic matter	Bulk density	Plasticity Index	Hydrogen potential	Free Swell Index	Cation Exchange Capacity	Specific surface area
ω (%)	OM(%)	$\rho(g/cm^3)$	PI(%)	pH	FSI	CEC $(meq/100g)$	SSA (m^2/g)
9.87	6.23	1.238	28	8.06	4	12.72	314.85

Table 2: Results of particle size analysis and hydraulic characterization tests

Particle size					Hydraulic parameter
Gravel (%)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Permeability coefficient k (m/s)
8	5	32	18	37	2.86 x 10^{-10}

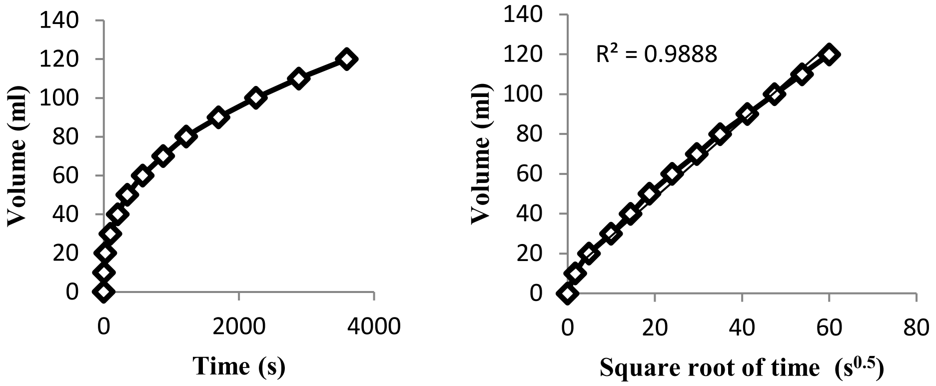
Table 3: Geotextile characterization results

Weight per unit area (g/m²)	Thickness (mm)
1106.9	2.13

Table 4: Results of characterization of assembled clay geosynthetics

Surface mass of dry clay (kg/m²)	Geotextile mass per unit area (kg/m²)	Thickness (mm)	Tensile strength (kN/m)	Strain at break (%)
7	8.06	9.06	PD: 2.03 CD: 14.46	PD: 9.4 CD: 41.14

*PD: Production Direction ; *CD: Cross Direction



Figures 5: Graphs of infiltrated volume over time (a) and its straight-line fit (b)

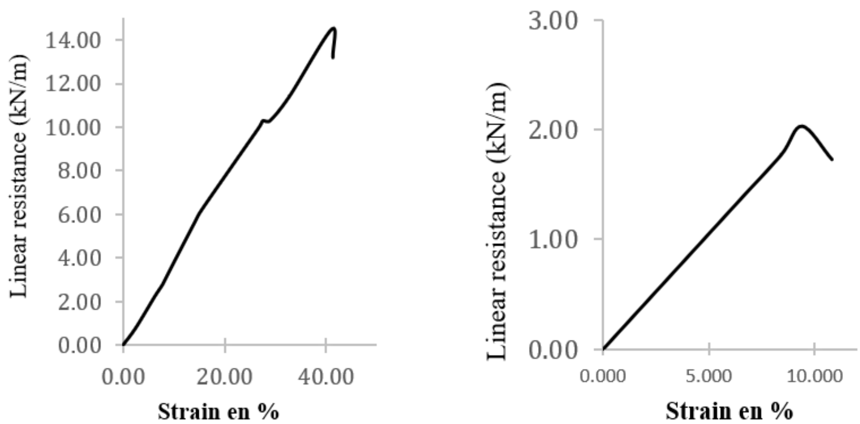


Figure 6: Evolution of linear tensile strength of clay geosynthetics in production direction (a) and cross direction (b)

Conclusions

The aim of this article was to explore the possibility of using clay and kenaf fibers from the localities of Toula and Nérékorosso in Burkina Faso, respectively, to manufacture a Geosynthetic Clay Liner. This approach contributes to the valorization of local resources while protecting groundwater resources. The project involved manufacturing a prototype GCL to reinforce the rapidly deteriorating protective technologies (polyane films) used on artisanal mining sites. The results of the physical and hydraulic characterization of the clay show characteristic values lower than those of the basic clays used to manufacture clay geosynthetics. The result is an illite-type clay with a permeability coefficient of 2.86×10^{-10} m/s and a swelling index of 4 ml/2g. Although the values obtained do not meet the criteria required for geosynthetics, a local clay-based geosynthetic was assembled on the assumption that the addition of bentonite could improve its properties and thus satisfy the primary objective of this study. Amending local clay with bentonite could improve cation exchange capacity, swelling and hydraulic conductivity. This addition should enable the geosynthetic to retain pollutants while limiting their migration into the subsoil.

The study also showed that kenaf fibers can be used to manufacture geotextiles for geosynthetic assembly. The results show that geotextile has a low tensile strength in the production direction (2.03 kN/m) compared with the required tensile strength (8 kN/m) for geosynthetics. On the other hand, in the cross direction, the maximum tensile strength of 14.46 kN/m is significantly higher than that required. This is due to the very tight or dense aspect of the wires in the cross direction, in contrast to the production direction where the wires are spaced apart. In the light of this analysis, it may be possible to reweave the geotextile by reducing the spacing between the longitudinal wires.

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