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THERMOMECHANICAL CHARACTERIZATION OF MIXTURES OF FRAKE CHIPS AND A CLAY MATERIAL FROM SEBIKOTANE FOR USE IN SOCIAL HOUSING

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ABSTRACT

With global warming, temperatures are increasing as the years go by and countries in the tropical area like Senegal are the first victim.
Indeed, this intensification in temperature causes thermal discomfort in the building, which leads to high energy costs.
To exterminate this phenomenon, the objective of this work is, from a clay material extracted in Sebikotane and the chips of Fraké (wood of scientific name: Terminélia superba [1]) which are abundant local materials, to make a thermo-mechanical characterization of the mixtures of these two materials in order to work out a material that not only enable to ensure a good thermal comfort in the building but also to reduce the cost of the construction.
Some mechanical and thermal attempts had been carried out on the samples taken and the analysis of the thermomechanical results made it possible to highlight the composition of the optimal mixture that could be used in social housing.
The optimal mixture acquired, guarantees a good thermal comfort but also a hugely sufficient mechanical resistance and it must be consisting of 3% of fraké chips and 97% of clay materials.

KEYWORDS: Characterization - Fraké chips - Clay material - Optimal - Thermomechanics

1. INTRODUCTION

The effects of climate change are so harmful to countries located in the tropical zone that is why scientists, all around the world are desirable to face that problem. Indeed, the increase in temperature combined with the non-respect of architectural construction standards (non-use of insulating materials in construction) leads to thermal discomfort in buildings. To compensate for this, the populations resort to cooling or air circulation devices, which explains the fact that in Africa buildings are responsible for 80% of energy expenditure and greenhouse gas emissions [2]. Appeal

In order to provide solutions that minimize the energy costs of buildings, many researchers have contributed by studying mixtures of materials known for their insulating power in order to find an optimal mixture that can improve the thermal comfort of the building.

Among the researchers who have looked into this, we can cite:
D. Sow et al who studied the mixture between rice straw and clay material and concluded that depending on the added rice straw the thermal conductivity of the mixtures decreases [3] ;

Bederina et al after working on the effect of wood shaving on the thermal conductivity of sand concrete, it is found that the thermal conductivity is improved by wood shaving [4] ;

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Meukam et al. aimed to determine the effect of adding pozzolan or sawdust to laterite soil bricks. The thermal properties showed that the incorporation of pozzolan or sawdust leads to a decrease in thermal conductivity. This is because the thermal conductivity remains under the influence of the water content in the material [5].

It is in this context that this article is written. In fact, our study consists of a thermomechanical characterization of fraké chips (tropical wood species) and a clay material for a possible use in social housing. Through this work, we could not only improve the thermal comfort in the building but also reduce considerably the price of the construction knowing that the basic materials used are local, available and very cheap. Mechanical and thermal tests were carried out using laboratory measurement methods and the results are analyzed and interpreted.

2. MATERIALS AND METHODS

The clay-based material is taken from Sébikotane in the Dakar region. These samples underwent different types of tests for geotechnical characterization before mixing them with the Fraké chips. Tests for the determination of the mechanical and thermal resistance were carried out to understand the thermomechanical behaviour of the mixtures.

a. Mechanical characterization

Tests like particle size analysis, sedimentometry, Atterberg limits, specific gravity and soil blue value were conducted on the clay material [6-11].

The specific gravity or absolute density of a soil is a quantity closely related to the mineralogy or chemical composition of the soil particles [12]. The test consists of measuring the specific weight of a soil using a pycnometer (or volumetric bottle).

The blue value is used to characterize the clay content of a soil. It is a quantity directly linked to the specific surface of the soil, in fact it represents the quantity of methylene blue which can be adsorbed on the external and internal surfaces of the clayey particles contained in the studied soil fraction.

After these tests, the clay material is mixed with fraké chips and its mechanical compressive strength is determined.

The hydraulic press (figure 1) allowed us to determine the mechanical compressive strength of 11x22cm cylindrical specimens of the different mixes after air-drying for 21 days.

In this test, the cylindrical specimen is placed between the plates of a press and the axial force is increased until the specimen breaks. The maximum value F of the force is used to calculate the axial compressive strength Rc of the material according to relationship (1) [13]:

$$\mathrm{Rc} = \frac{\mathrm{F}}{\mathrm{S}} \quad (1)$$

Table 1 shows the composition of each mixture.

Table 1: Mixture composition

Mixture	Clay (%)	Chips (%)	Clay (g)	Chips (g)
Raw material	100	0	5000	0
Mixture 1	99	1	4950	50
Mixture 2	98	2	4900	100
Mixture 3	97	3	4850	150
Mixture 4	96	4	4800	200
Mixture 5	95	5	4750	250

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Figure 1: Crushing of a specimen with a hydraulic press

b. Thermal characterization

The Hot Wire technique is the classical transient method for measuring the thermal conductivity of insulating materials. The device (Figure 2) consists of a thermal shock probe, to be placed between two identical samples of the material to be characterized, an electronic acquisition box and a graphical interface type software to control the tests and process the results [14], [15].

Considering the assumptions of radial heat transfer in a semi-infinite medium, the value of the temperature of the wire of length (l) can be approximated as a function of the heat flux φ created by the wire and the thermal conductivity λ by the expression (2):

$$T(t) = \frac{\varphi}{4\pi l\lambda} Ln(t) \quad (2)$$

Plotting T(t) as a function of ln(t), the slope α of the linear part of the curve allows us to calculate the thermal conductivity as follows (3):

$$\lambda = \frac{\varphi}{4\pi l\alpha} \quad (3)$$

Figure 2: Hot wire technique

2. RESULTS AND DISCUSSION

a. Mechanical results

The particle size plus sedimentometry analysis of the clay material showed that 88% of the sample passed through the 80µm sieve (Figure 3). It also showed that the sample consists of 1% gravel, 7% coarse sand, 30% fine sand, 23% silt and 39% clay.

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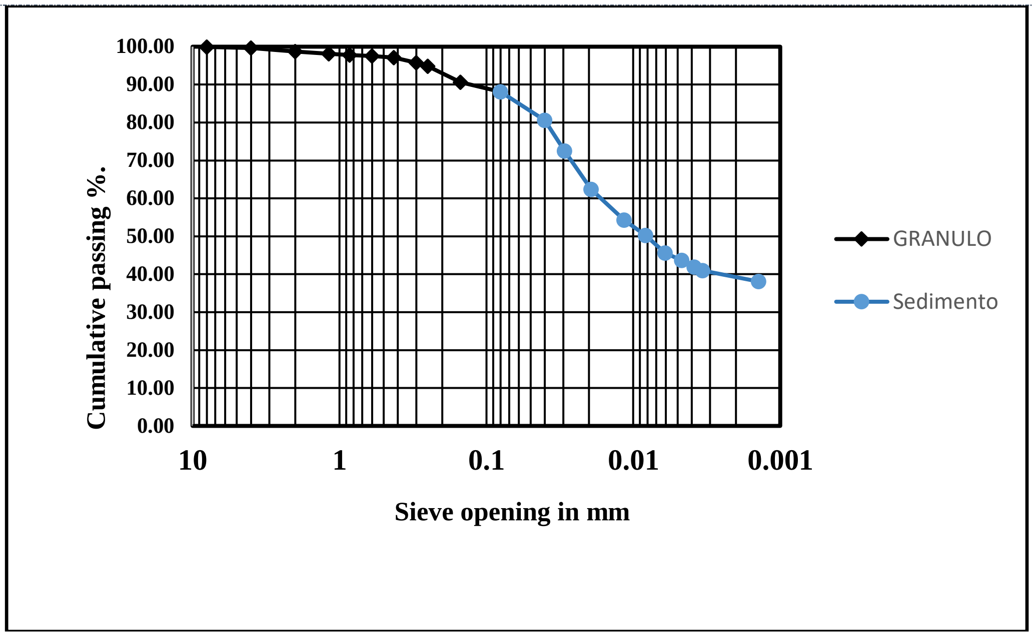

Figure 3: Granulometry + sedimentometry

After performing the tests for the determination of the Atterberg limits, the results gave a liquidity limit (W_L) of 66%, a plasticity limit (W_P) of 39.84% and a plasticity index (Ip) of 26.16%.

The value of the plasticity index indicates that our sample is moderately plastic, which can be explained by the presence of 39% clay in the material.

The value of the shrinkage limit shows us that below a water content of 19.89% our material is solid without shrinkage.

Figure 4 reports the results obtained from the Atterberg limits of our clay material on a diagram defining the consistency state of the sample:

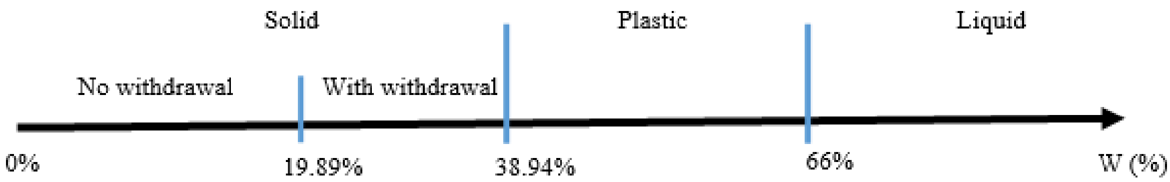

Figure 4: Consistency diagram of clay material

The determination of the specific weight of the clay material gave a specific weight value of 2.37g/cm3. This last one informs us on the mineralogy of our clay sample and it is included between 1 and 2.60g/cm ^{3} what means that the clayey material is an organic soil.

The methylene blue test otherwise known as the stain test gave a VBS of 3.95, which shows that the sample is silty-clay with medium plasticity.

Compression tests of the mixtures were carried out using a hydraulic press after air-drying for 21 days with slight shrinkage.

Figure 5 shows the evolution of the average compressive strength for each mix as a function of the percentage of chips.

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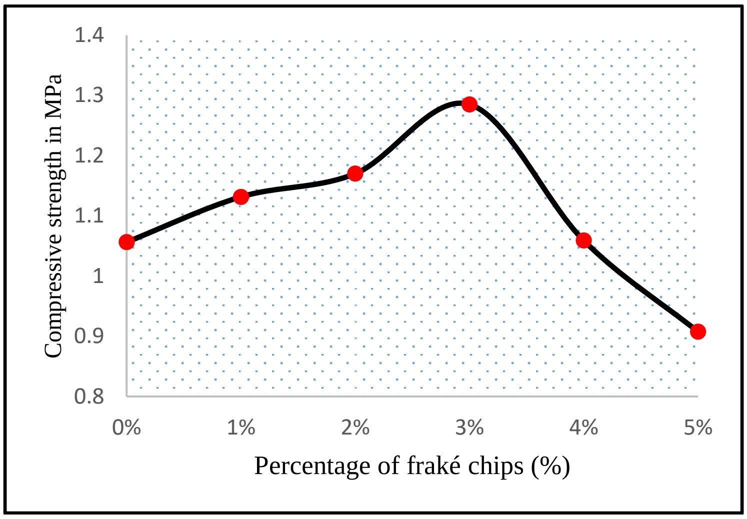

Figure 5: Compressive strength as a function of percentage of chips

At 0% chips, we have a strength of 1.056Mpa. This resistance increases with the percentage of chips until it reaches a maximum value of 1.285MPa at 3% by mass of chips and then it decreases progressively to 0.908Mpa at 5% by mass of chips.

Thus, we can notice that the mixture with 3% by mass of chips provides the best compressive strength (1.285MPa). It should be noted that beyond 5% by mass of chips, mixing becomes very tedious. The difficulty of having completely homogeneous mixtures can be at the origin of the low compressive strength obtained.

b. Thermal results

The thermal characterization consists in determining the thermal conductivity and the thermal resistance of the mixtures. Having the thermal conductivity, we determined the thermal resistance considering a 20 cm thick wall. Table 2 and Figure 6 show the conductivity and thermal resistance values as a function of the percentage of wood chips in the mixture.

Table 2: Thermal results

Mixtures	Conductivity λ W.m-1.K-1	Thermal resistance Rth m².K.W-1
0%	0.98	0.20
1%	0.86	0.23
2%	0.63	0.32
3%	0.51	0.39
4%	0.42	0.47
5%	0.35	0.57

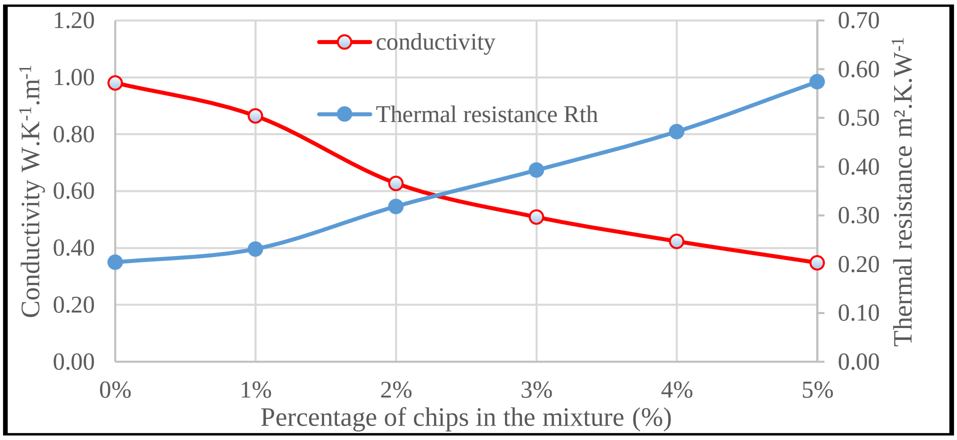

Figure 6: Evolution of conductivity and thermal resistance as a function of the percentage of chips for a 20cm wall

If we look at the thermal resistance, we realise that it is as increasing as the percentage of chips in the mixture is increasing.

Indeed, from 0.20 K.m^2.W^{-1} for the pure mixture, it increases to 0.39 K.m^2.W^{-1} at 3% of chips before rising to 0.57 K.m^2.W^{-1} for a percentage of chips of 5%.

c. Thermo#mechanical results

Having the mechanical and thermal behaviour of our mixtures, we can then deduce the thermomechanical behaviour of the latter.

To do this, the study consists in superimposing (figure 7) the curve of the compressive strength and that of the thermal resistance according to the percentage of fraké chips in the mixture.

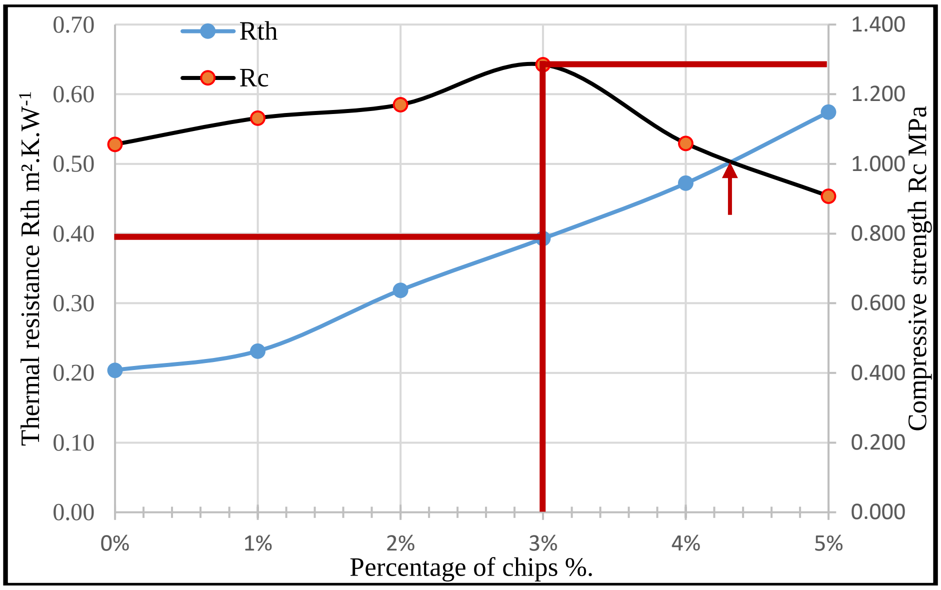

Figure 7: Thermomechanical results

Figure 7 shows that at 3% of fraké chips in the mix, the compressive strength Rc is at its maximum and beyond this value it crumbles as the percentage of chips increases.

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This may be due to two factors:

- The low mechanical inertia of the fraké chips, which become increasingly important in the mix.
- The non-homogeneity of the mixture, which beyond 3% of chips is very difficult to implement.

As for the thermal resistance of the mixture, it increases with the percentage of fraké chips. The insulating character of the fraké chips, which have a low conductivity, can explain this.
The superposition of the two curves also allows us to see:

- The point of intersection between the two curves coincides with 4.3% of chips, a mechanical resistance equal to 1 MPa and a thermal resistance equal to 0.5 $K.m^2.W^{-1}$.
- At 3% of chips, the compressive strength is maximum and is equal to 1.285 MPa while the thermal resistance is equal to 0.39 $K.m^2.W^{-1}$.

The comparison of these two results shows that at the intersection point, the thermal resistance is better than the 3% chips in the mix but the compressive strength at 3% is almost 1.3 times higher than that at the intersection point.

However, for safety reasons, mechanical resistance is preferred to thermal resistance. It is important to have good mechanical resistance while ensuring good thermal comfort in the building.

It is in this logic that the mixture constituted by 3% of fraké chips and 97% of clayey material is identified as being the optimal thermomechanical mixture with a mechanical resistance of 1.285 MPa and a thermal resistance of 0.39 $K.m^2.W^{-1}$.

Taking the pure mixture, i.e. with 0% chips, as the basic mixture, a comparative study made with the mixture showing the optimal thermomechanical behaviour.

The mechanical resistance Rc is 22% higher than the pure mixture and the thermal resistance is 95% higher.
The determination of the density of the mixture gave a value of 1800 $Kg.m^3$.

Moreover, to build a 3-metre high non-load-bearing wall with this material of such a density, the lower brick (which supports the ones above it) must have a minimum strength of 0.054 MPa. This means that the compressive strength is more than sufficient.

3. CONCLUSION

The main objective of our study was the thermomechanical characterization of mixtures of fraké chips and a clay material for a possible use in social housing. The study of these mixtures allowed highlighting an optimal mixture from which we had a good thermomechanical resistance.

After analysing the geotechnical properties of the clay material, it appears from the thermomechanical studies of the mixtures that the optimal thermomechanical mixture is made up of 3% of fraké chips and 97% of clay material. Indeed, this mixture ensures a good thermal resistance and a sufficient mechanical resistance for a filling wall in a building for residential use.

It should be noted that the basic materials used during the construction are local, available and inexpensive. Their uses do not stop only for the improvement of thermal comfort in the building, indeed they can greatly contribute to the reduction of the cost of construction.

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