Research Article
Integration of Agricultural Waste in Local Building Materials for their Exploitation: Application with Rice Straw

[1]D. Sow, [2]M. Ahmat Chafadine, [1]S. Gaye, [1]M. Adj and [3]I.K. Cisse
[1]Laboratoire d'Energétique Appliquée, Ecole Supérieure Polytechnique de Dakar,
Université Cheikh Anta DIOP de Dakar, Sénégal
[2]Université de Sarl, Tchad
[3]Laboratoire de Matériaux Mécanique et Hydraulique, Ecole Polytechnique de Thiès, Sénégal

Abstract: Through experiments, we have determined the mechanical and thermal properties of samples. This allowed us to determine the most optimal formulations. Therefore, we have prepared samples constituted by two basic materials, clay and laterite, mixed with rice straw. Thus, agriculture is among the economic sectors that produce more waste. The latter are mainly the straw of the three most-produced cereals in the world: wheat, corn and rice. Concerning rice straw, its high content of cellulose makes it difficult to digest. So, few animals are able to use it as food. Most of the straws are lost, buried, burned or used as litter. Moreover, clay and laterite formations represent the most abundant materials resources in Africa. So, this study has allowed us to show that the integration of rice straw in lateritic and clay soils for its use as building materials will allow, in addition to its recycling, to greatly reduce the social habitat cost and to improve the thermal comfort.

Keywords: Agricultural waste, clay, laterite, mechanical properties, rice straw, thermal properties

INTRODUCTION

According to the Agency for Environment and Energy Management (ADEME) 375 million tonnes of waste are produced per year which makes it the first economic sector producer of waste, before the activity of the building and public works.

Among the main agricultural wastes we have the straws of the three most produced cereals in the world: wheat, corn and rice. The proportion of straw consumed by cattle is very low. It would be only 15% worldwide for the straw of corn and rice.

In fact, rice straw is rich in cellulose. Consequently, only animals capable of digesting cellulose (rabbit, horse, etc.) use it as food. The majority is lost, buried, burned or used as bedding (Institut National de la Recherche Agronomique, France, 1987).

Moreover, the soil is used economically on the spot for millennia. More than 30% of the population habitats worldwide are made of soil. Whether raw, cooked or stabilized, varieties of earthen architectures have abounded since the appearance of humans throughout the world (African Journal of Science and Technology, 2004).

The soil is generally used in laterite or clay states and which represent the most abundant and economical materials resources in Africa (BCEOM-CEBTP, 1975).

In our researches we are interested in the valorization of rice straw through its integration in construction materials.

Thus, the main objective of this research is to optimize the mechanical and thermal properties of laterite and clay soils mixed with rice straw for possible use in buildings construction.

MATERIALS AND METHODS

We used a hydraulic press to perform compression strength tests (Norme AFNOR, 1981a, b, 1995; Dupain et al., 2000; Gaye, 2001).

We used the boxes method and the hot plate method to perform thermal conductivity tests (Bal, 2001; Voumbo et al., 2010; Gaye et al., 2004).

RESULTS AND DISCUSSION

Basic materials used:
Straw: In 1955, the West Africa Rice Development Association (WARDA) and the Senegalese Institute for Agricultural Research (ISRA) have proposed to develop three new rice varieties (Sahel 108, Sahel 201 and Sahel 202) that are most suitable for irrigated rice producers of the Valley of Senegalese River.

Table 1: Varieties of rice

Variety	Number of days after sowing for irrigation stoppage	Number of days after sowing for its harvest
Sahel 108	95	110
Sahel 201	110	125
Sahel 202	105	120

Sahel 108 variety has been targeted for the dry season because its cycle is the shortest and allows farmers to make a double farming (Table 1).

To make our samples, we have chosen this rice straw of variety Sahel 108, which is locally the most available.

The straw we used comes from Dagana, town located at 408 km from Dakar (Senegal).

We have stabilized the straw by drying it in the sun until all the harmful water has evaporated (Bayer and Waters-Bayer, 1999). The maximum water content of straw must be between 15 and 20% what will render enzymes inactive and stop the development of the moulds (Institut National de la Recherche Agronomique, France, 1987).

Laterite: The laterite we used to make our samples come from Montrolland, town located at 87 km from Dakar (Senegal). We considered the fraction of the laterite passing the 5 mm sieve to make our samples.

The sieve and sedimentation analysis of this laterite soil separate has shown 25% of gravel, 15% of coarse sand, 25% of fine sand, 6% of silt, 29% of clay and 52% of the grains mass pass the 80 μm sieve (Fig. 1).

Consequently, the effects of particle size distribution on the behavior of lateritic soil are important (Norme AFNOR, 1990, 1991; Holtz and Kovacs, 1991).

Moreover, The Atterberg limit tests that we made have allowed us to note that the plasticity index of Montrolland's laterite is 19.74% and its liquid limit is 41.70% (Fig. 2).

Consequently, these values do not presage an important withdrawal after drying bricks manufactured on the basis of this raw material.

Thus, the water effects on the soil's behavior are without much importance (Norme AFNOR, 1990, 1991).
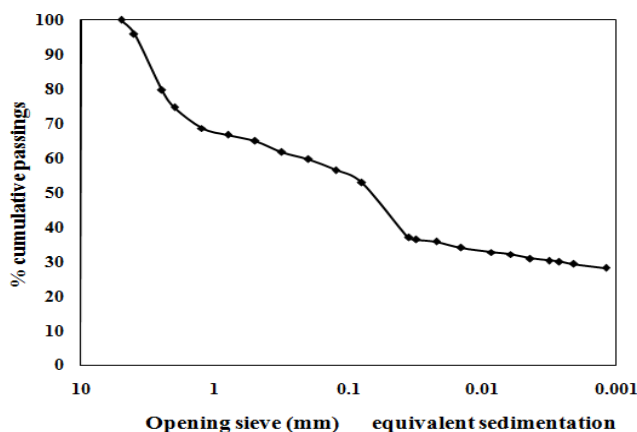

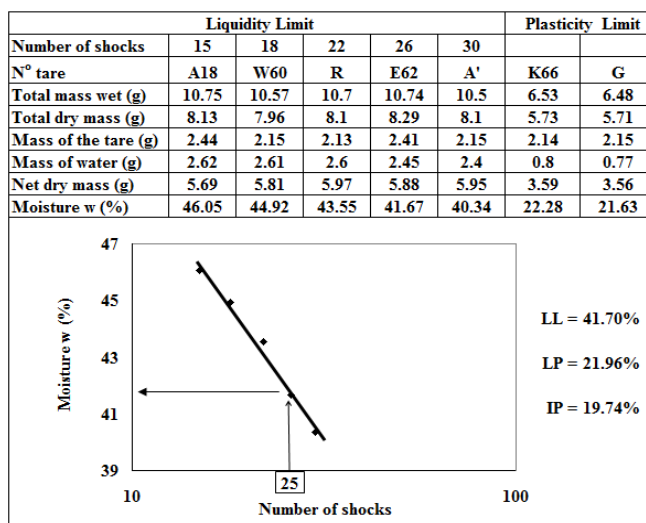Fig. 1: Size analysis and sedimentation analysis of montrolland's laterite

	Liquidity Limit					Plasticity Limit	
Number of shocks	15	18	22	26	30		
N° tare	A18	W60	R	E62	A'	K66	G
Total mass wet (g)	10.75	10.57	10.7	10.74	10.5	6.53	6.48
Total dry mass (g)	8.13	7.96	8.1	8.29	8.1	5.73	5.71
Mass of the tare (g)	2.44	2.15	2.13	2.41	2.15	2.14	2.15
Mass of water (g)	2.62	2.61	2.6	2.45	2.4	0.8	0.77
Net dry mass (g)	5.69	5.81	5.97	5.88	5.95	3.59	3.56
Moisture w (%)	46.05	44.92	43.55	41.67	40.34	22.28	21.63

Fig. 2: Atterberg limits of laterite montrolland
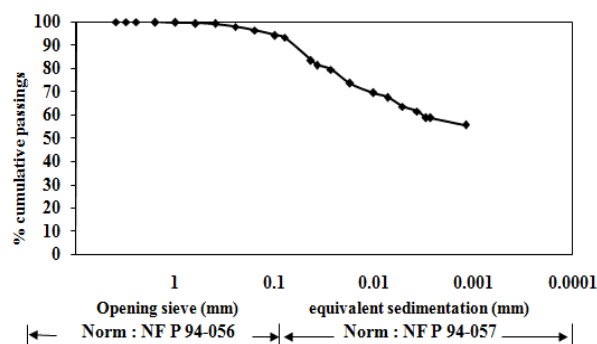
Fig. 3: Sieve and sedimentation analysis of sébikotane's clay

	Liquidity Limit					Plasticity Limit	
Number of shocks	22	25	27	30	36		
No tare	25	K	C20	Y3	A18	I6	F56
Total mass wet (g)	10.86	10.75	10.88	10.4	10.85	6.29	6.59
Total dry mass (g)	6.65	6.59	6.8	6.4	6.81	4.95	5.19
Mass of the tare (g)	2.2	2.13	2.41	2.09	2.39	2.21	2.42
Mass of water (g)	4.21	4.16	4.08	4	4.04	1.34	1.4
Net dry mass (g)	4.45	4.46	4.39	4.31	4.42	2.74	2.77
Moisture w (%)	94.61	93.27	92.94	92.81	91.40	48.91	50.54

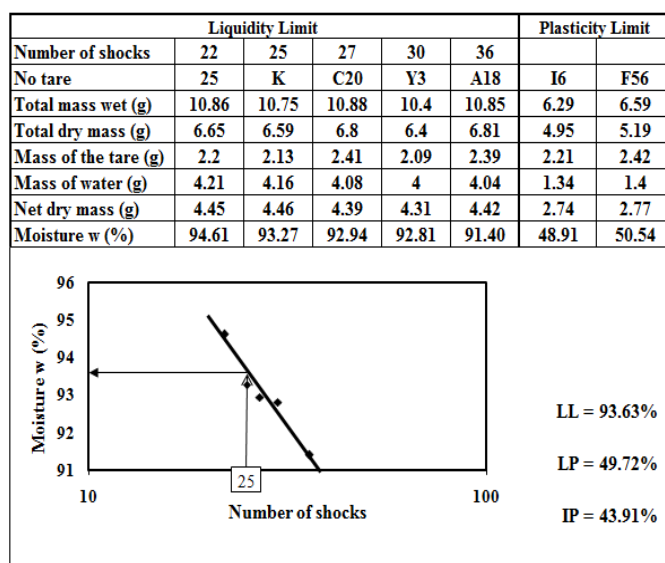LL = 93.63%

LP = 49.72%

IP = 43.91%

Fig. 4: Atterberg limits of sébikotane's clay

Clay: The clay soil we used to make our samples comes from Sébikotane town located at 40 km from Dakar (Senegal).

The sieve and sedimentation analysis of this clay soil show 3% of coarse sand, 24% of fine sand, 15% of silt, 58% of clay and 90% of the grains mass pass the sieve 80 μm (Fig. 3).

Thus, the effects of particle size distribution on the behavior of soil are not very important (Norme AFNOR, 1990, 1991; Holtz and Kovacs, 1991).

Furthermore, The Atterberg limit tests that we made allow us to note that the plasticity index of Sébikotane's clay is 43.91% and its limit liquidity is 93.63% (Fig. 4). Consequently, these values presage an important withdrawal after drying bricks manufactured based on this raw material.

Thus, the water effects on the behavior of soil are very important (Norme AFNOR, 1990, 1991).

Mechanical characterization:
Mixtures of laterite and straw: The Fig. 5 shows the results of compression strength of straw mixed with laterite.
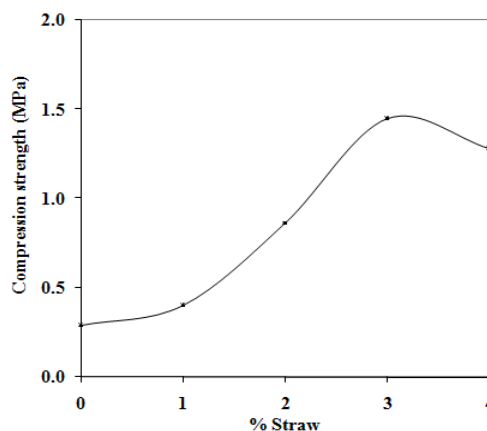

Fig. 5: Evolution of compression strength according to the percentage of straw mixed with laterite

We notice, from Fig. 5, an increase of compression strength according to the percentage of straw in the mixture. But from 3%, it starts to decrease.

Indeed, above this percentage, it is very difficult to obtain a homogeneous mixture of straw and laterite.
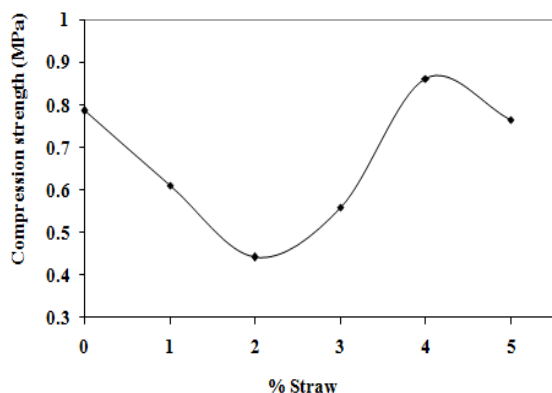
Fig. 6: Evolution of compression strength according to the percentage of straw mixed with clay

Furthermore it should be noted that from 4% mixing mixtures is almost impossible.

Therefore, we can consider that the optimum is 3% of straw and 97% of laterite.

Mixtures of clay and straw: The Fig. 6 shows the results of compression strength of straw mixed with clay.

We notice, from Fig. 6, a decrease of compression strength according to the percentage of straw in the mixture. It is from 2% that the effect of the frame starts being felt, thus an increase of compression strength.

From 4.2% of straw compression strength starts decreasing.

In fact, beyond this percentage it is difficult to have a homogeneous mixture.

Furthermore, it is important to note that from 5% the mixing of mixtures is almost impossible.

Thus, we can consider that the optimum is at 4.2% of straw in the mixture.

Thermal characterization:
Straw: Values of conductivity and thermal resistance of the straw alone, in relation with the density, are represented on the Table 2.

We notice that the conductivity of the straw increases according to density. What causes a reduction of the thermal resistance according to the density.

Indeed, values in Table 2 show that the straw alone is a good thermal insulation (Gaye and Menguy, 2008).

This confirms that the construction of wooden-frame houses with straw filling improves thermal comfort.

Mixtures of laterite and straw: The Fig. 7 shows the evolution of the thermal conductivity according the percentage of straw mixed with Montrolland laterite.

This Fig. 7 shows that the thermal conductivity decreases according the percentage of straw. It's due to

Table 2: Different values of the thermal conductivity and thermal resistance of a wall of 20 cm of straw, according to the density

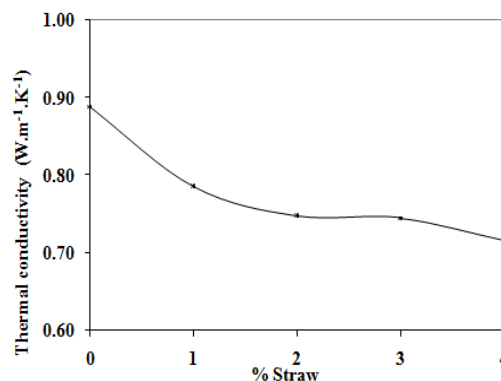| Density (kg/m^3)	Thermal conductivity (W/m/K)	Thermal resistance for e = 20 cm (m^2.K/W)
45.440	0.043	4.651
47.456	0.049	4.082
55.456	0.052	3.846

Fig. 7: Evolution of the thermal conductivity according to the percentage of straw mixed with laterite
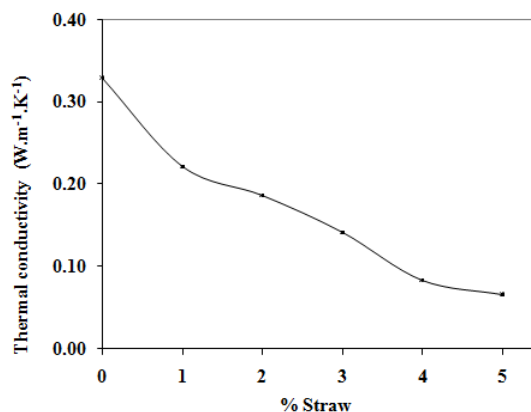

Fig. 8: Evolution of thermal conductivity according to the percentage of straw mixed with clay

the fact that the straw has a thermal conductivity lower than that of laterite soil.

Mixtures of clay and straw: The Fig. 8 shows the evolution of the thermal conductivity according the percentage of straw mixed with Sébikotane clay.

This Fig. 8 shows that the thermal conductivity decreases according the percentage of straw like Fig. 7.

Thermo-mechanical results:
Mixtures of laterite and straw: To have in parallel the thermal and mechanical characteristics, we represented them in Fig. 9.

This Fig. 9 shows that the most optimal mixture is composed of 3% straw and 97% laterite soil. This
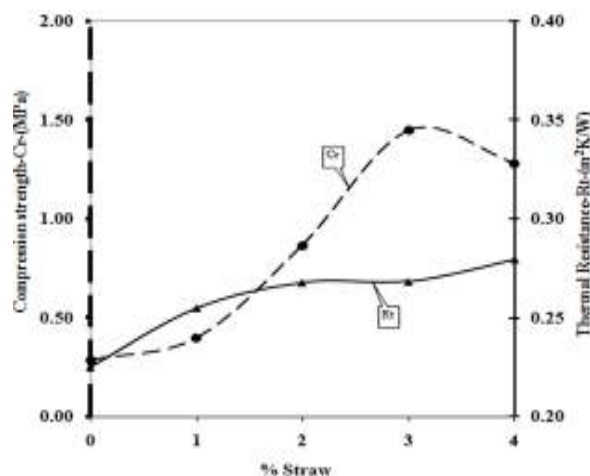
Fig. 9: Evolution of compression strength and thermal resistance based on the percentage of straw mixed with laterite for a wall thickness of 20 cm

Table 3: Characteristics of materials developed

	Straw + sébikotane clay	Straw + montrolland laterite
Straw %	4.200%	3%
Soil %	95.800%	97%
Mechanical resistance	0.863 MPa	1.448 MPa
Thermal resistance	2.500 m^{2}K/W	0.268 m^{2}K/W

Table 4: Size composition of the sébikotane clay and montrolland laterite

	Sébikotane clay (mass %)	Montrolland laterite (mass %)
Gravel	0	25
Coarse sand	3	15
Fin sand	24	25
Silt	15	6
Clay	58	29
<80 μm	93	52

Indeed, if we consider a non-bearing 4 m height wall built with this optimal composition of 1240 kg/m^3 density. The base of the wall must have at least a compression strength of 0.05 MPa. This is much lower than the mechanical resistance to compression of the optimal formulation.

Comparative study: Table 3 shows that the compression strength is higher for developed straw + Montrolland laterite material for the developed straw + Sébikotane Clay material. Unlike the mechanical resistance, the same table shows that the thermal resistance is lower for the straw + Montrolland laterite material than for the straw + Sébikotane Clay material.

These differences can be explained by the percentage of fine which is higher in Sébikotane clay (93%) than in the laterite (52%). This results in a higher percentage of gravel in the laterite (25%) than in Sébikotane clay (0%) (Fig. 1 to 3 and Table 4).

These results confirm that the effects of particle size distribution on the behavior of clay are not important, while these effects are important in the behavior of laterite.

Therefore, it is normal that the compression strength of the straw + laterite material (1.448 MPa) is higher than that of the straw + Clay material (0.863 MPa).
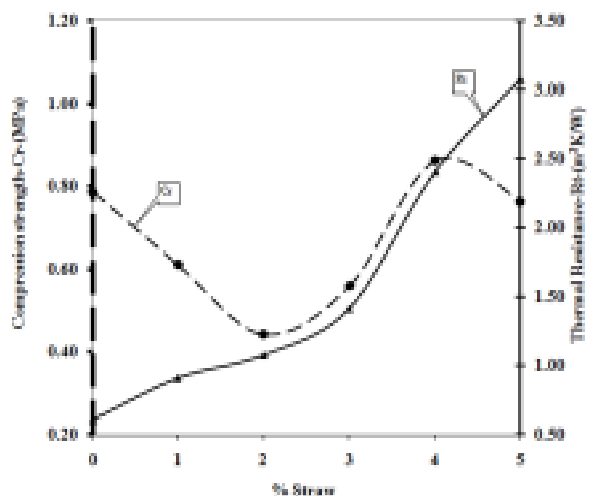

Fig. 10: Evolution of compression strength and thermal resistance according to the percentage of straw mixed with clay for a wall thickness of 20 cm

mixture has a thermal resistance of 0.268 m^{2}K/W and a compression strength of 1.448 MPa.

Indeed, if we consider a non-bearing 4 m height wall built with this optimal composition of 1482 kg/m^3 density. The base of the wall must have at least a 0.06 MPa compression strength. This is much lower than the mechanical compression strength of the optimal formulation.

Mixtures of clay and straw: Figure 10 shows the evolution of the thermal and mechanical resistance, depending on the percentage of straw mixed with clay for a wall thickness of 20 cm. We find that the most optimal mixture is composed of 4.2 and 95.8% of straw clay soil. This mixture has a thermal resistance of 2.5 m^{2}K/W and a compression strength of 0.863 MPa.

CONCLUSION

At the end of our study, we note that:

- Proceeding to mixtures of clay and laterite soil with straw, we were able to optimize the thermo-mechanical properties of materials.
- The first and most optimal mixture, composed of 4.2% of rice straw and 95.8% of Sébikotane clay, has a compression strength of 0.863 MPa and a thermal resistance of 2.50 m^{2}K/W.
- The second and most optimal mixture composed of 3% of rice straw and 97% of Montrolland laterite,

has a compression strength of 1.448 MPa and a thermal resistance of 0.268 m^{2}K/W.

- The material that has the best features for the construction of buildings for residential use is the second mixture if the mechanical resistance is favored. If we want a better thermal comfort the first mixture has to be chosen.

The interesting results obtained allow to identify the best soils which can be part of the constitution building materials. Finally, these results will allow, in addition to valorizing the agricultural waste, to reduce the cost of social housing and improve thermal comfort.

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