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Evaluation of the Mechanical Behavior of Clay Bricks Stabilized at 4% Cement and Mixed with Limba Wood Waste

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Abstract: In this study, the authors evaluated the mechanical behavior of bricks made of clay material stabilized with 4% cement and mixed with different contents (0; 2; 4; 6 and 8%) of limba wood waste (sawdust and chips). The clayey raw material ANMK was characterized by the method of X-ray diffraction (XRD) on oriented sheets (normal, glycol and heated to 490°C), by scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). The chemical and mineralogical compositions of cement used were determined by inductively coupled plasma – optical emission spectrometry (ICP-OES) and by X-ray diffraction. This clay material consists of 96% kaolinite and 4% of the chlorite / montmorillonite interstratified. The morphology of the material observed by scanning electron microscopy showed an irregularity of clusters. The elementary analysis by energy dispersive spectroscopy shows that this material is essentially aluminosilicate. The chemical analysis of the cement showed a predominance of CaO (67%) and SiO_2 (21%), however the mineralogical analysis showed the presence of calcite, alite, hatrurite and brownmillerite. This clay material has a mass shrinkage on drying of 26.6% and the linear shrinkage is 6.4%. The formulation with sawdust appears to give greater flexural and compressive strengths than those obtained with chips.

Keywords: Clay Brick, Cement, Wood Waste, Mechanical Behavior, X-ray Diffraction

1. Introduction

This study is part of the valorization of local materials by making bricks in clay material stabilized with cement and mixed with wood waste. The use of wood waste could be considered as an alternative to environmental protection [1-3] and could help reduce the cost of construction through bricks going with thermal comfort. Many works on the elaboration of terracotta composite materials using plant waste [2, 4-7] were studied and very little in stabilized soil [8]. From these studies, it appears that the incorporation of plant waste reduces the mechanical resistance of the manufactured bricks. Several studies have been carried out on the stabilization of raw earth-based construction materials by organic and / or mineral binders [9], by gum arabic and reinforced by rice straw [10] and by sugar cane molasses [11]. In this study, the authors will attempt to evaluate the mechanical behavior using two types of limba wood waste, such as sawdust and chips.

2. Materials and Methods

The clay material ANMK was collected during the rainy season in the city of Makoua at 150 meters from the Likouala-Mossaka river (figure 1) on the side of the

Champagnat college. The soil profile, presented (figure 2) shows two phases: an upper phase (between approximately 0 and 0.5 meters in depth) of black color, mainly constituted of organic matter and a lower phase (beyond 0.5 meters in depth) yellowish in color, consisting of a soil that grabs the fingers and tongue. This soil is used in the local brickyard for the manufacture of solid bricks. The sampling area is marked by low grass as shown in Figure 3 showing the general view of the ANMK material sampling site.

Figure 1. *Likouala – Mossaka river.*

Figure 2. *Soil profile.*

Figure 3. *Vegetation of the site.*

The wood waste (sawdust and chips) from limba were taken in a sawmill in the Pokolo district located in the Sangha department, Republic of the Congo. The X-ray diffraction measurements of the ANMK material were carried out at the laboratory of the Geological and Mining Research Office (BRGM) in Orléans (France). They were carried out on a Siemens D5000 automated diffractometer using the the cobalt $K\alpha$ ray with the wavelength λ = 1.789 Å. The data were recorded over an angular range ranging from 4 to 84°, with a counting time of 2 seconds per step for analyzes on oriented slides of the fraction less than 2 µm; the sample rotating in the angular range from 2 to 36°. The processing of the diffractograms and the quantification of the mineral species were carried out using the Diffrac. Suite software. On the other hand, the XRD measurements of the cement were carried out on a Panalytical X'Pert Pro MPD diffractometer with Bragg Brentano θ-2θ geometry using the copper anticathode with a wavelength λ = 1.54056 Å. The data processing was done with QualX software with the Powcod database. The morphology and elementary analyzes of the ANMK material were carried out by scanning electron microscopy (SEM) and by energy dispersive spectroscopy (EDS). The determination of the calcium carbonate content of the clay material by calcimetry was carried out according to the NF P 94 – 048 [12] standard; the sample was previously dried and ground into a powder with a particle size of less than 80 µm. The geochemical analysis of the cement used was carried out with an ICP - OES Icap 6500 radial torch device from Thermo. The briquettes measuring 16 cm × 4 cm × 4 cm were produced according to the formulation "clay stabilized at 4% cement and mixed with different wood contents (sawdust or chip)" with the wood waste content varying from 0 to 8% using the modified ASTM D698 method for compaction. The briquettes were dried at room temperature for 28 days. The mechanical tests were carried out with a tree-point flexul device according to the NF P 15 – 451 [13] standard and with an IGM brand apparatus (general measurement engineering) for the compressive strength according to the NF EN 196 – 1 [14] standard.

3. Results and Discussion

3.1. Mineralogical Analysis by X-ray Diffraction

The figure 4 shows the results of mineralogical analysis of the ANMK clay material:

The analysis of the normal spectrum shows the appearance of the peak at the inter-reticular distance d = 14.16 Å which could correspond to either smectite, chlorite or the smectite / chlorite interstratified; the appearance of the peak at d = 7.15 Å which would correspond to either kaolinite or chlorite and that at d = 3.579 Å could correspond to kaolinite. Examination of the spectrum treated with ethylene glycol does not show any modification in the inter-reticular distance. On the other hand, by examining the spectrum at 490°C, the authors note the disappearance:

a. peak at d = 7.15 Å which confirms the presence of kaolinite. This result is due to the transformation of kaolinite into metakaolinite, which is an amorphous phase, following the departure of the water constituting the kaolinite [15, 16].

b. from the peak at d = 14.16 Å to give a peak at d = 10.28 Å which reflects the loss of interfoliar water from the smectite [7, 17]. The ANMK clay material consists of 96% kaolinite and 4% of the smectite / chlorite interlayer. These results are in agreement with those found by [3, 6].

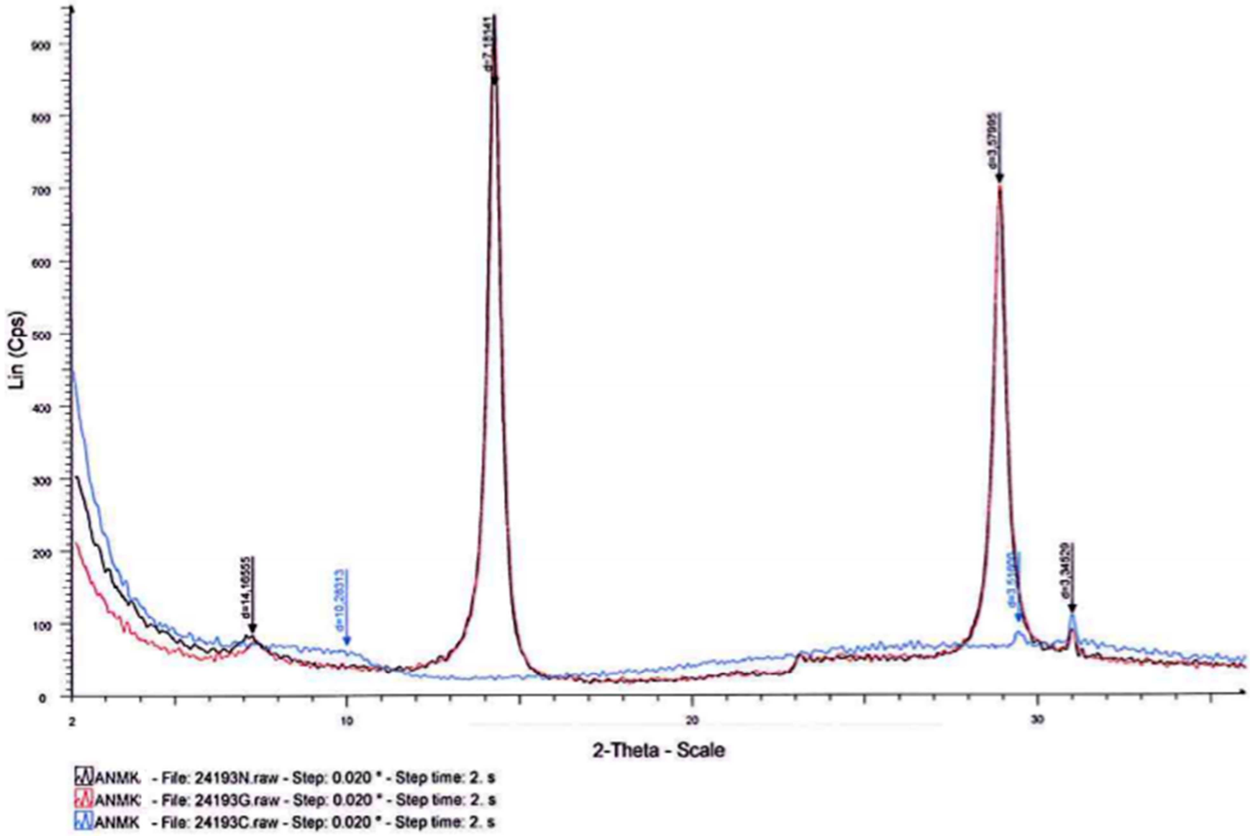

Figure 4. *Diffractogram on oriented plates normal (N), glycol (G), heated (C).*

3.2. Scanning Electron Microscopy and Energy Dispersive Spectroscopy

The image transmitted by secondary electrons obtained for the ANMK material is presented in figure 5.

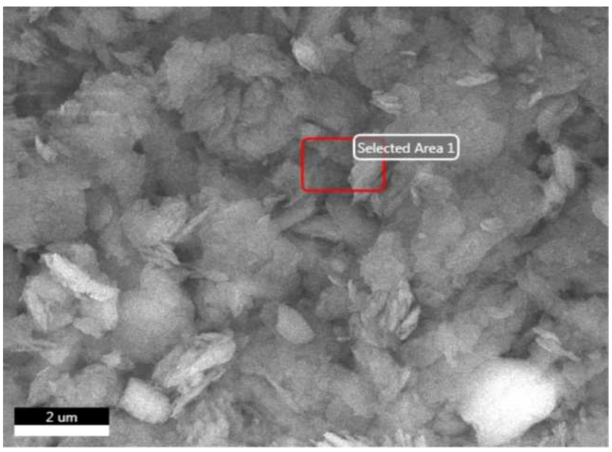

Figure 5. *Morphologie of ANMK material.*

The particles of this material appear in the form of clusters with irregular contours. What could be a morphology encountered by poorly crystallized kaolinite. This observation was also made by [3, 18, 19].

The figure 6 shows the spectrum of the elementary analysis by EDS of the selected area of the ANMK material.

This EDS spectrum shows that the chemical composition of the material is predominated by the elements Si, Al and Fe and is essentially aluminosilicate. It also reveals the presence of the carbon peak indicating the presence of impurities of organic matter in the material.

3.3. Calcimetric Analysis

The calcium carbonate content is 0.6%. The ANMK material is therefore not rich in calcium carbonate. These results are in agreement with those observed by the EDS analysis which does not show the presence of calcium.

3.4. Chemical and Mineralogical Compositions of Cement

The chemical analysis of the cement used (Figure 7) reveals the predominance of CaO (67%) and SiO_2 (21%). It is mainly used in concrete for buildings and civil engineering works. Therefore, this cement is Portland type.

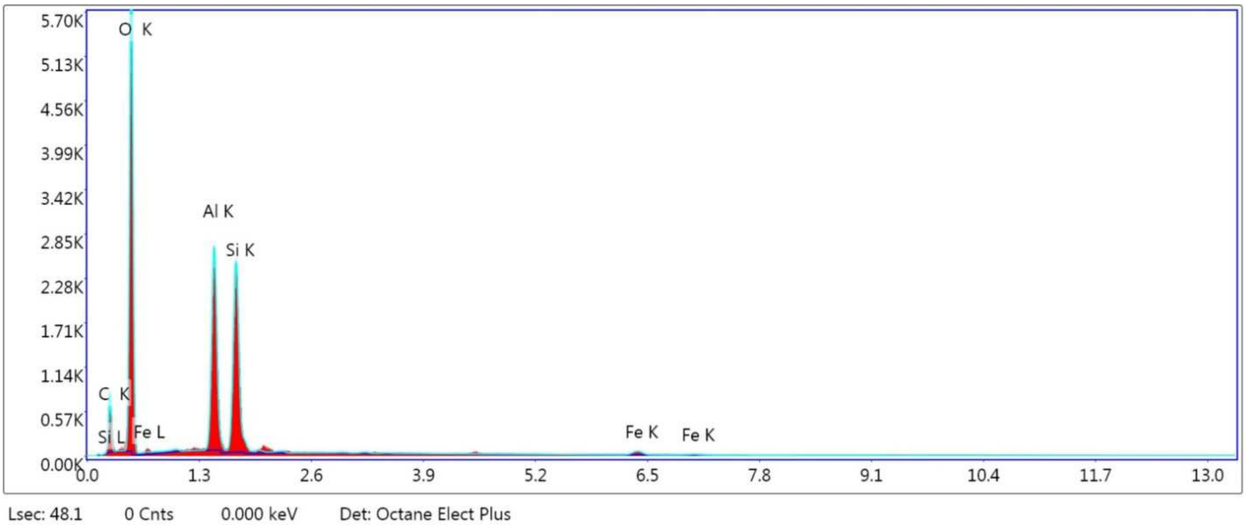

Figure 6. *Elementary analysis spectrum of ANMK material.*

Table 1. *Elementary analysis of ANMK material.*

eZAF Smart Quant Results			
Element	**Weight (%)**	**Atomic (%)**	**Error (%)**
C K	19.77	27.37	10.65
O K	56.14	58.36	8.45
Al K	11.77	7.26	5.12
Si K	11.36	6.73	5.14
Fe K	0.95	0.28	17.08

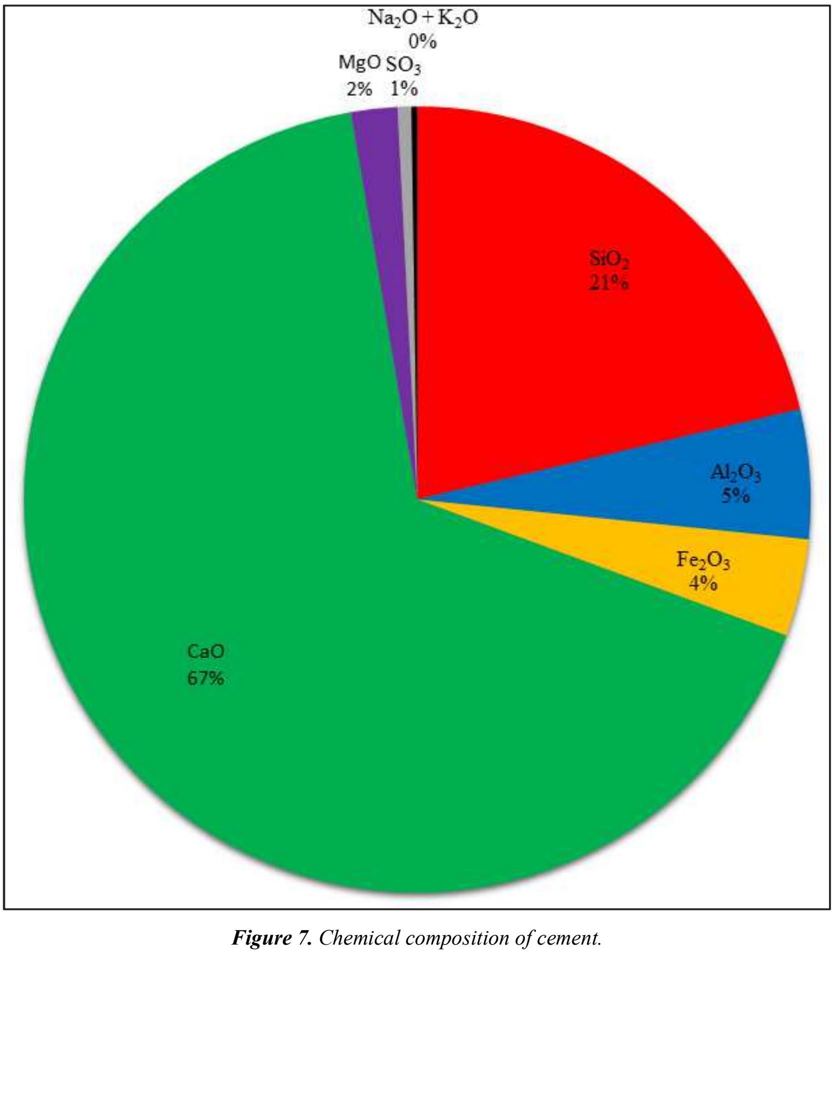

Figure 7. *Chemical composition of cement.*

This figure 8 shows the X-ray diffraction spectrum of the cement used.

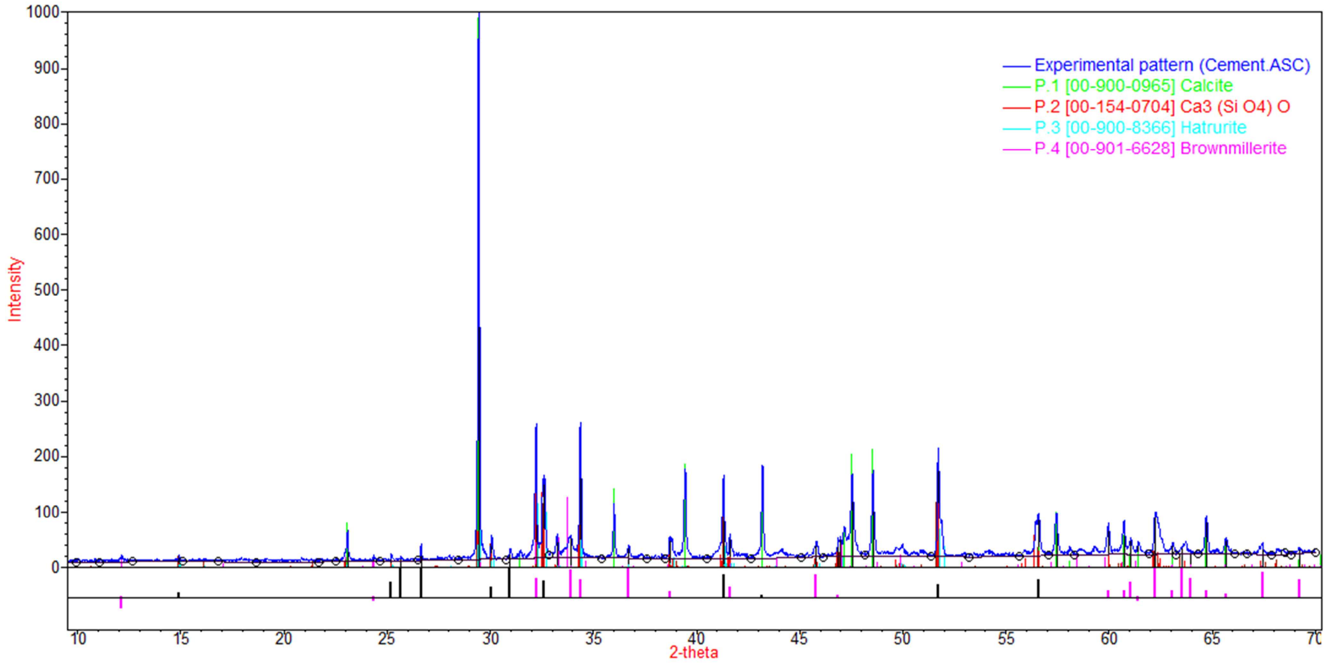

Figure 8. *XRD spectrum of cement.*

The Analysis of the XRD data shows the presence of calcite, alite, hatrurite and brownmillerite as shown in the table below:

Table 2. *Mineralogical composition of cement.*

Mineral species	Chemical formula	Estimated percentage (%)
Calcite	$CaCO_3$	45.1
Alite	Ca_3SiO_5	27
Hatrurite	$Ca_{27}O_{45}Si_9$	21.5
Brownmillerite	$Ca_2Fe_2O_5$	6.4

3.5. Monitoring of Mass and Linear Shrinkage During Drying of the ANMK Material

The figure 9 shows the variation in mass shrinkage and linear shrinkage on drying for ten days of the ANMK material.

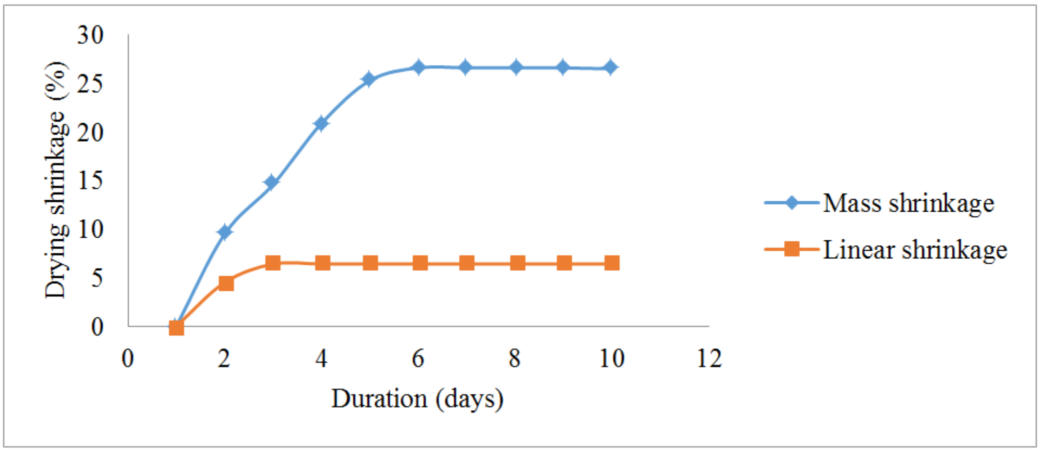

Figure 9. *Variation of mass and linear shrinkage.*

This material has a mass shrinkage on drying of 26.6%. The mass of the briquette becomes constant from the sixth day. On the other hand, the linear shrinkage is 6.4% and this shrinkage is constant from the third day of drying.

3.6. Mechanical Behavior

3.6.1. Flexural Strenght

The figure 10 shows that whatever the wood waste content, the incorporation of limba sawdust into within the clay bricks appears to give flexural strengths greater than those given by wood chips. This could be explained by the fact that larger pores would form in the chip formulation than in sawdust. This figure shows that the variation in flexural strength of bricks as a function of sawdust content has a minimum of 4% sawdust and 6% limba wood chips.

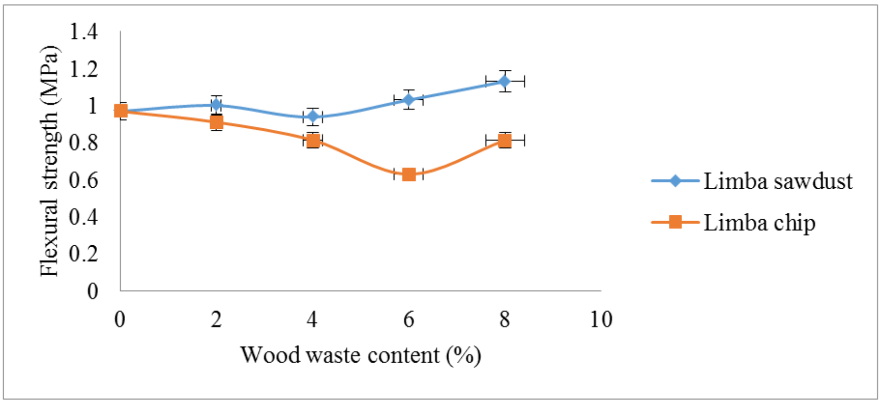

Figure 10. *Flexural strength according to the content of limba wood waste.*

The resistance to the flexural in this study are within the limits of acceptability for these briquettes to be used in construction. The flexural strength standards imposed by several countries are between 0.5 - 1 MPa [20]. We have found that whatever the formulation, the flexural strengths obtained respect this range of values.

3.6.2. Compressive Strength

The analysis of figure 11 shows that the behavior of the compressive strength is identical whatever the nature of the wood waste used. The variation in compressive strength as a function of the wood waste content has a minimum of 4% sawdust content and 6% limba wood chips. The sawdust seems to give resistances greater than that of chip above 4%. This could be explained by the fact that much larger pores would form with the chips and lead to the brittleness of the briquettes.

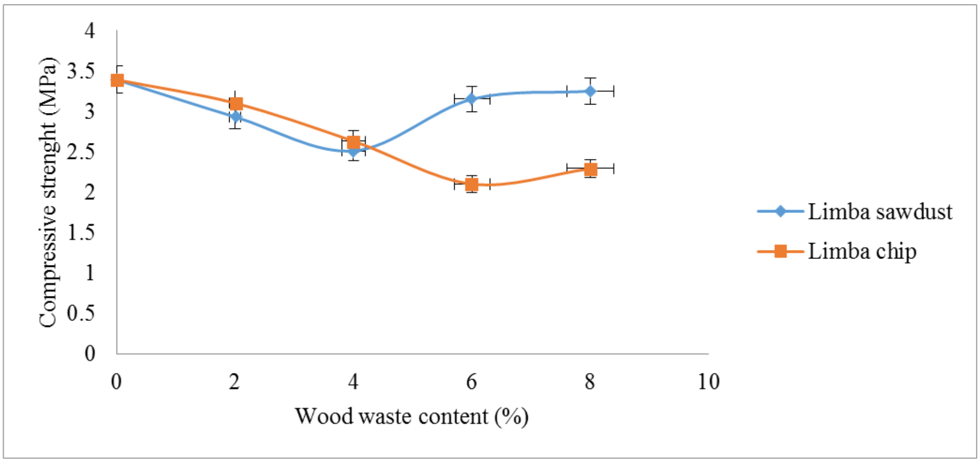

Figure 11. *Compressive resistance according to the content of limba wood waste.*

The standards for the use of compressed earth bricks found in the literature mainly concern compressive strength. In some countries there have been standards for the use of compressed earth bricks in construction for some years ago. These standards vary from country to country and are between 1 - 4 MPa [20]. The compressive strengths obtained in this study meet these different standards; they could be improved by the compaction process.

4. Conclusion

In this study, the authors performed X-ray diffraction, scanning electron microscopy, and energy dispersive spectroscopy to determine respectively the mineralogical composition, morphology and elementary composition of the clay material, and these analyzes showed that this material is of the kaolinitic type, essentially aluminosilicate and low in calcium carbonate. The chemical analysis of the cement showed the predominance of CaO (67%) and SiO_2 (21%). The results of mechanical tests have shown that sawdust seems to give the best resistance compared to chips. The flexural strength has a minimum of 4% sawdust and the compressive strength has a minimum of 6%. The mechanical strengths obtained in this study meet the requirements of compressed earth briquettes used in construction. These resistances could be improved by the high pressure compaction process. A study to understand the effects of this vegetable waste on the fire resistance of these briquettes is in progress.

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