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Recovering wood wastes for potential use in building

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Abstract

Wood shavings which are waste products of the wood industries have been regrouped under the basis of their sizes in three classes. For every class, wood concretes prismatic samples of 4x4x16 cm3 dimensions have been prepared from the mixture of Bubinga wood shavings and Portland cement. Their physical (densities, water absorption rate) and mechanical (flexural and unconfined compressive strength) characteristics have been studied during 8 years. The results we obtained tend to show that the mechanical and physical characteristics of wood concrete are stable and depend: on the wood shavings class and the quantity of cement that have been used for their manufacture. The main result of this survey is that: the wood concrete so made can be used to produce chipboards for walls and insulations materials.

Keywords: Wood shavings; Wood concrete; Flexural strength; Compressive stress

1. Introduction

he prohibitively expensive building costs in Cameroon marginalize at least 95% of middle-class households who lack sufficient financial income to acquire a decent house. Strategies put in place in the building sector to reduce costs in order to increase access to lodging by the majority propose the use of local building materials. However, in forests zones where traditional aggregates such as sands and gravels are scarce, wood industry produces wastes such as wood shavings and sawdust which are either thrown away or used as combustible.

In a bid to upgrade these wastes and in light to the work of Moslemi et als. (1983), Hachmi et als. (1990), and Oyagade A. (1992), Sousa et al (2004) and Mahyuddin et als.(2010), we intend to examine the possibility of using wood shavings as light aggregates to produce concrete. Wood concrete thus produced could help to improve housing in Cameroonians forest zones. This paper will be structured in five (5) sections: it will presents: Materials and Methods (Section 2), results (Section 3)and the possibilities of use wood concrete (Section 4) will precede the conclusion (Section 5).

2. Materials and methods

The materials consisted of Portland cement, water and wood shavings

2.1. Cement

The Portland cement used is manufactured by the Cameroon Cement Company (Cimencam) and it is sold in 50 kg bags on the Cameroonians market. The characteristics of Portland cement used in the tests are displayed in Table 1.

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Table 1 Characteristics of the cement used (Mamba M. (2011)

Class of cement	Manufacturer	Colour	Specific density	Apparent density	Setting time
CPJ35	Cimencam	grey	3.1	1.17	3 hours

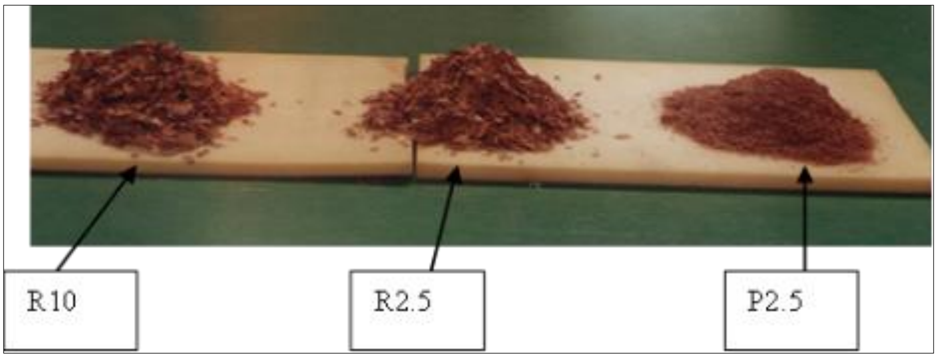
2.2. Water

Water used is captured from the Nyong River that flows through the Cameroonian city of Mbalmayo and distributed by the national water corporation (la Camerounaise Des Eaux (CDE) after treatment at the Akomnyada station.

2.3. Wood shavings

Shavings used in this study are reddish in colour and all come from the Bubinga wood. This species was chosen because of the study carried out on it. The chemical composition provided by CIRAD 1999 reveals that Bubinga wood contains less than 1% of silica and a maximum of 40% of Cellulose. Results from the studies carried out by Mamba et al. 2014 on the Bubinga PH show that the PH of this species is acidic. As concerns its physical and mechanical properties, results from CIRAD 1999 and the Tropical Forest Technical Center 1990 indicate that Bubinga belongs to the category of heavy wood (density higher than 0.8) and is very hard, with flexural strength higher than 100MPa. These shavings were collected from some woodworking plants around Yaoundé and then sequenced through two grids in order to classify them according to size (Mahyuddin et al(2010), Aziz et al (1981), Oyagade et al(1992)). Thus, three classes of shavings were obtained:

- The R10 class which includes shavings whose dimension is higher than 10 mm (These are oversize's from sieves with 10mm aperture meshes)



Picture 1 Different classes of wood shavings

- The R2.5 class corresponds to shavings whose dimensions are lower than 10mm and higher than 2.5mm. They pass through a screen whose meshes have a 10mm aperture and are screen oversize from a sieve with 2.5 mm mesh aperture.
- The P2.5 class. These are shavings that go through a sieve whose meshes have a 2.5 mm aperture.

The objective of this classification is to detect a possible influence of shavings dimension on the wood concrete properties. Table 2 gives apparent density values of various classes of wood shavings that we measured. You will notice that their values increase as the size of shavings diminishes.

Table 2 Apparent volume masses of various categories of Bubinga chips

Class	R10	R2,5	P2,5
Apparent density (g/litre)	56	96	208
Colour of chips	reddish	reddish	reddish

2.4. Cement dosage

For reasons of simplicity, we have chosen to define the cement dosage as the weight of binder per volume unit (m^3) of dry materials (cement + wood shavings). In fact, when we mix the weight of Cement « P_{cement} » with a given weight of wood shavings « $P_{shavings}$ », the cement dosage of wood concrete « d_{dosage} » is obtained through the equation (1):

$$d_{dosage} = \frac{P_{cement}}{V_{app\ cement} + V_{app\ shavings}} \qquad (\mathrm{Kg}/m^3) \qquad \text{…………..(1)}$$

Where: $V_{app\ cement}$ and, $V_{app\ shavings}$ are apparent volumes of cement and wood shavings The corresponding content of cement is obtained through the relation (2):

$$T = \frac{P_{ciment}}{P_{shavings}} \qquad \text{…………(2)}$$

If ρ_{cement} and $\rho_{app\ \ shavings}$ are apparent density of cement and wood shavings, the apparent volumes of cement and wood shavings are obtained from equations (3) and (4).

$$V_{app\ cement} = \frac{P_{cement}}{\rho_{app\ cement}} \qquad \text{…………………(3)}$$

$$V_{app\ shavings} = \frac{P_{shavings}}{\rho_{app\ shavings}} \qquad \text{…………… (4)}$$

In this study, we have chosen Cement dosages of 250, 300, 350, 400, 450, 500 et 600 kg/ m^3 . In order to take into account, the fact that; the maximum volume of laboratory mix is 5 litres, with the relations (1) and (2), we obtained Tables 3, 4, and 5 which give us the various formulations used for the manufacturing of prismatic samples wood concrete for each class of wood shavings. One should notice that: for each class, there is a minimal dosage below which it would be impossible to produce wood concrete samples. These dosages are 250kg/m3 for R10 and R2.5 classes, and 500Kg/m3 for P2.5 class. The minimum dosages were determined by using the following procedure: wood shavings of different classes were mixed with quantities of binder obtained from decreasing cement dosage up to a value below with it will not be possible to produce a wood concrete test specimen.

Table 3 Wood concrete formulation for R10 wood shavings class

Dosage (Kg/ m^3)	**600**	**500**	**450**	**400**	**350**	**300**	**250**
Cement (kg)	3.00	2.50	2.25	2.00	1.75	1.50	1.25
$V_{shavings}$ (in litres)	2.44	2.87	3.08	3.30	3.51	6.72	3.94
$P_{shavings}$ (in g)	136.40	160.50	172.30	184.25	196.25	208.20	220.15
Cement content	22.00	15.57	13.05	10.85	8.92	7.20	5.67

Table 4 Wood concrete formulation for R2.5 wood shavings class

Dosage (Kg/ m^3)	**600**	**500**	**450**	**400**	**350**	**300**	**250**
Cement (kg)	3.00	2.50	2.25	2.00	1.75	1.50	1.25
$V_{shavings}$ (in litres)	2.44	2.87	3.08	3.30	3.51	6.72	3.94
$P_{shavings}$ (in g)	233.85	274.85	295.35	315.90	336.40	356.90	377.40
Cement content	12.82	9.10	7.61	6.33	5.20	4.20	3.30

Table 5 Wood concrete formulation for P2.5 wood shavings class

Dosage (Kg/ m^3)	**600**	**500**
Cement (kg)	3.00	2.50
$V_{shavings}$ (in litres)	2.44	2.87
$P_{shavings}$ (in g)	506.65	595.55
Cement content	5.92	4.20

2.5. Procedure for fabricating prismatic wood concrete

The production of 4x4x16 cm3 test prismatic wood concrete was done according to the following procedure:

- According to the formulation of wood concrete, the known weights of Portland cement and water were homogeneously mixed using electrical mixer. The mixer was done in order to ensure an even distribution of cement in the mixture.
- When a water cement mixture becomes homogeneous, a known weight of wood shavings was gradually incorporated to the mixture.
- When the mixture made up of cement, water and wood shavings is blended (for 2 or 3minutes), the moulds are lubricated.
- After 2 or 3 minutes, the mixture of wood shavings, cement and water is homogeneous and we obtain a plastic wood concrete.
- We put plastic wood concrete into the lubricated moulds. This is done in two layers. Each layer being subjected to 8 shocks.
- Moulds containing wood concrete are kept and covered with a waterproof polyane film to prevent rapid water evaporation.
- One or two days after their manufacture, the wood concrete samples are unmolded labelled and stocked under a polyane film which will be removed 15 days later.

Picture 2 Wood concrete specimens

2.6. Experimental program

2.6.1. Flexural test

Before being tested, « j » days old prismatic wood concrete are weighed and their dimensions measured in order to get their density.

The test was performed according to ASTM D 1635-00-2006 procedure. It was carried out using a suitable apparatus mounted for this purpose (Figure 1). The procedure run on "j "old specimens was as follows:

- Two steel rollers were placed at a distance of 10,00cm apart on the bottom plate of hydraulic machine. They were cylindrical (10cm long and had a diameter of 0,5 cm). The wood concrete sample was placed over the two steels supports.
- One loading steel roller identical to the two described above was set on top of the sample. The horizontal distance between the axis of the loading steel roller and the bottom steel roller is . This steel roller laid between the sample and the head of testing machine.
- The specimen was loaded at the controlled rate of 0.25bar/minute since a hydraulic machine was used.
- The load strain at failure was recorded. It was a maximum load that the specimen could carry in flexion.

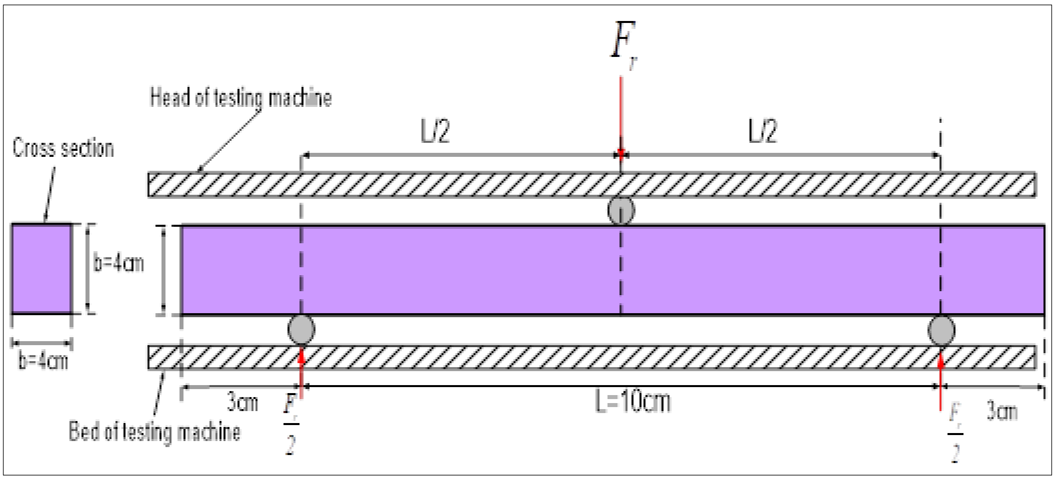


Figure 1 Setup used for testing the flexural strength

At failure point the maximum bending moment is $M_f = F_r \frac{L}{4}$ and the corresponding flexural stress σ_f will be obtained by relations (5) or (6):

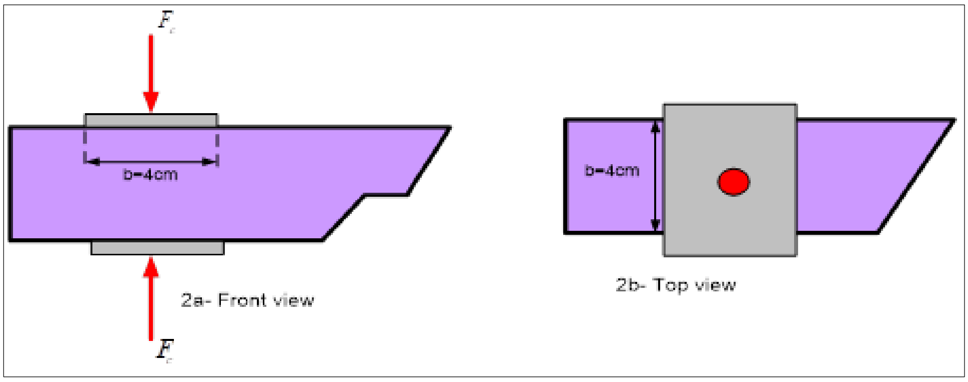


Figure 2 Setup used for testing the unconfined compressive strength

$$\sigma_f = \frac{M_f}{I/V} \qquad (5)$$

But $V = \frac{b}{2}$ et $I = \frac{b^4}{12}$

Therefore

$$\sigma_f = \frac{1.5 F_r L}{b^3} \qquad (6)$$

2.6.2. Compression tests

The test procedure was the same as ASTM D2166-00e1-2004. The half wood concrete sample obtained after breaking at flexion are put into a compressive press (hydraulic machine) that can be schematized as shown in Figure 2. The specimen was loaded at controlled rate of 0.5bar/minute since hydraulic machine was used. The load strain at failure was recorded. It is the maximum load the specimen could carry in compression.

At failure, the corresponding compressive stress is obtained through the following relation:

$$\sigma_c = \frac{F_c}{b^2} \qquad (7)$$

The flexural strength value used in this paper is a mean obtained from three tests, and compressive strength value; the mean obtained from the six half specimen provided from the three test prismatic samples used during flexion tests.

When these tests are carried out of water, we talk of dry flexural or compressive strength. The wet flexural and compressive strength are gotten from the tests achieved on samples that from the 28th days of their manufacture have been immersed in water during 6 days.

2.6.3. Water absorption rate

This test is realized on 28 days old samples. Depending on the submersion time, the relation between the quantity of water absorbed by one specimen and its dry mass is calculated. This relation is called water absorption rate.

The 28 days old specimens were totally immersed in water for "j" days. They were then taken out, wiped with a cloth and weighed. This wet weight M_h of each specimen was recorded. The specimens were stored in the stream to dry up for 24hours. The temperature of the stream was 105°C during this period. After drying, the specimen was weighed once more. This dry weight M_s of specimen was recorded again. The specimen water absorption rate after "j" days of immersion $T_{w.J}$ is given by the following relationship:

$$T_{w.J} = \frac{M_h - M_s}{M_s} 100 \qquad (8)$$

3. Result and discussion

3.1. Apparent density (Figure 3)

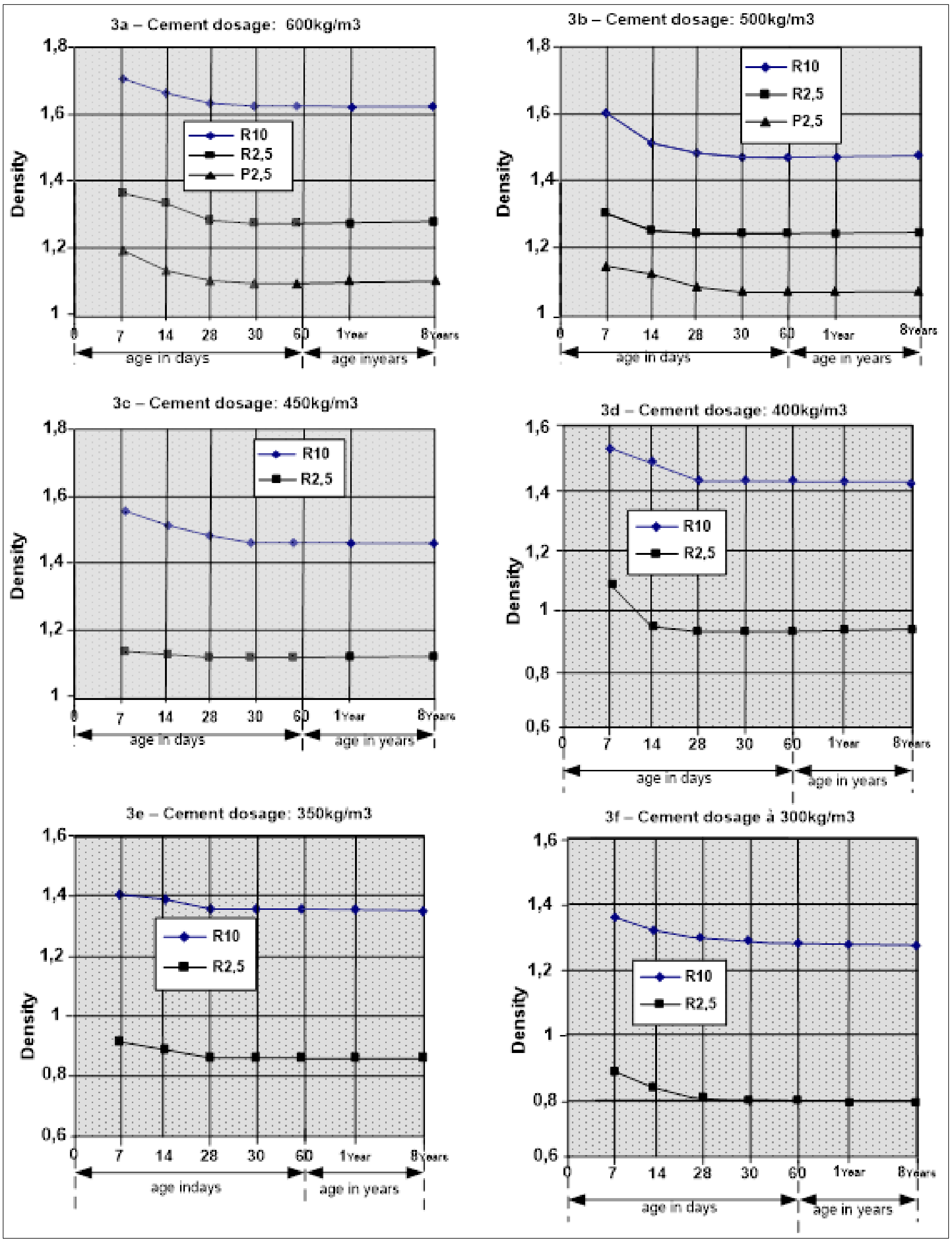


Figure 3 Wood concrete density according to cement dosage and age

3.2. Influence of cement dosage

While observing the curves indicating density of wood concrete specimens according to cement dosage, one notes that: density increases when the level of cement dosage increases. One notices that: whatever the level of cement dosage the highest densities of wood concrete specimens are obtained with R10 class and the lowest with P2.5 class. It should be noted that these densities vary between 1.71 and 0.80, which seem to indicate that mixtures of cement and wood shavings (wood concrete) belong to light concrete category.

3.3. Influence of age

At this stage, we can notice that the density of all specimens decreases with age. This decrease is higher during the first 14 days and seems to stabilize beyond the 28th day and even after 8 years! These decreases can be explained by the fact that a certain quantity of water that does not participate in cement hydration reactions is lost through evaporation.

So for 28days old specimens; the highest density of 1.64 (for cement dosage of 600 kg/m3) is given by the R10 category test tubes and the lowest, 0.80 (for cement dosage of 300 kg/m3) by those of the R2.5 category. For wood concrete specimens whose cement dosage is 250 kg/m3, it was not possible to measure their density due to their irregularities.

3.4. Dry compressive stress

Results for dry compressive stress of various wood concrete specimens according to the cement dosage and age are presented in Figures 4.

3.4.1. Influence of cement dosage on dry compressive stress

The dry compressive data (Figure 4) shows that stress increases with cement dosage irrespective of the wood shavings class. Whatever the dosage, the highest dry compressive stresses are obtained with R10 class and the lowest with P2.5 class. The high dry compressive stress produced with R10 category chips can be explained by the fact that their dimensions (that are at least equal to 10mm) are higher than those of other categories and can therefore mobilize more friction at the level of the cement-fibre interface.

3.4.2. Influence of age on dry compressive stress (Figure 4)

While observing the evolution of curves showing the dry compressive stress according to age, we can notice that stress increases as age increases. A high increase in dry compressive strength is observed up to the 28th day and beyond and even stabilizes 8 years later.

Irrespective of age, it is also observed that the highest dry compressive strength is given by wood concrete produced with R10 class wood shavings and the lowest with those of P2.5 class wood shavings.

At 28 days: the highest dry compressive stress, which is 19,65 MPa, is obtained with R10 class wood shavings for a 600kg/m3 cement dosage. For dosages between 400 and 300 kg/m3, one notices that the dry compressive strength of specimens using R10 class wood shavings range between 10,00MPa and 6,20MPa, and that of specimens using R2.5 class wood shavings vary between 3,60MPa and 1,80MPa. To this effect, it would be interesting to know that these resistances are similar to those of other types of light concrete. Thus for example, the compressive stresses of vermiculite concrete ranges between 2,00 and 3,00MPa and the compressive stresses of cellular concrete lower than 8,00MPa.

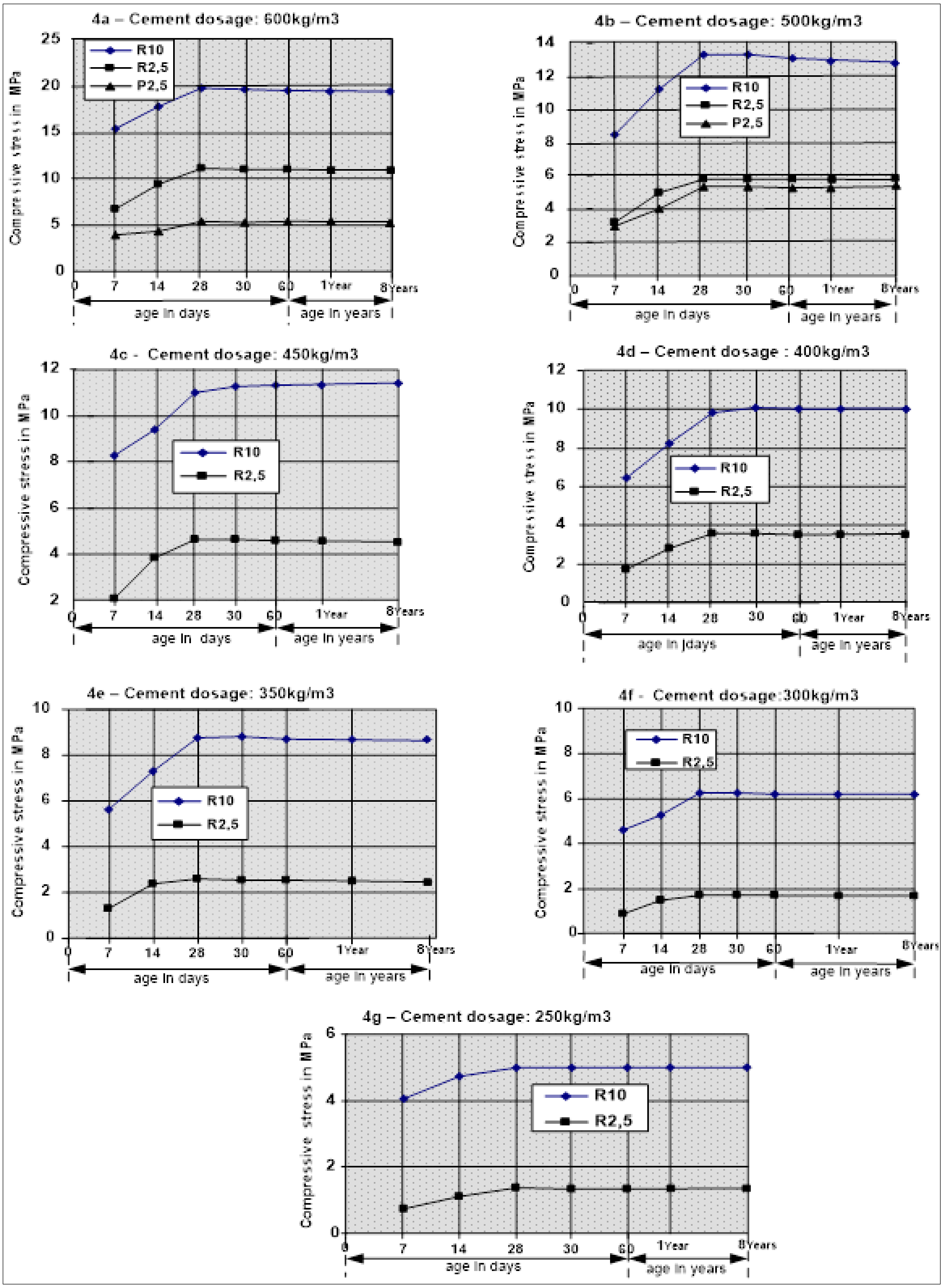


Figure 4 Dry compressive stress according to cement dosage and age

3.4.3. Dry flexural strength (Figure 5)

Comments on dry compressive stress in the paragraph above can easily be transposed to the values of dry flexural strength. We would only insist on the fact that; during compressive or flexion tests, we observed that wood concrete specimens underwent major deformations before breaking. Test specimens giving: the biggest deformations are those that have been produced with R10 class wood shavings and the smallest deformations by specimens prepared with P2.5 class wood shavings.

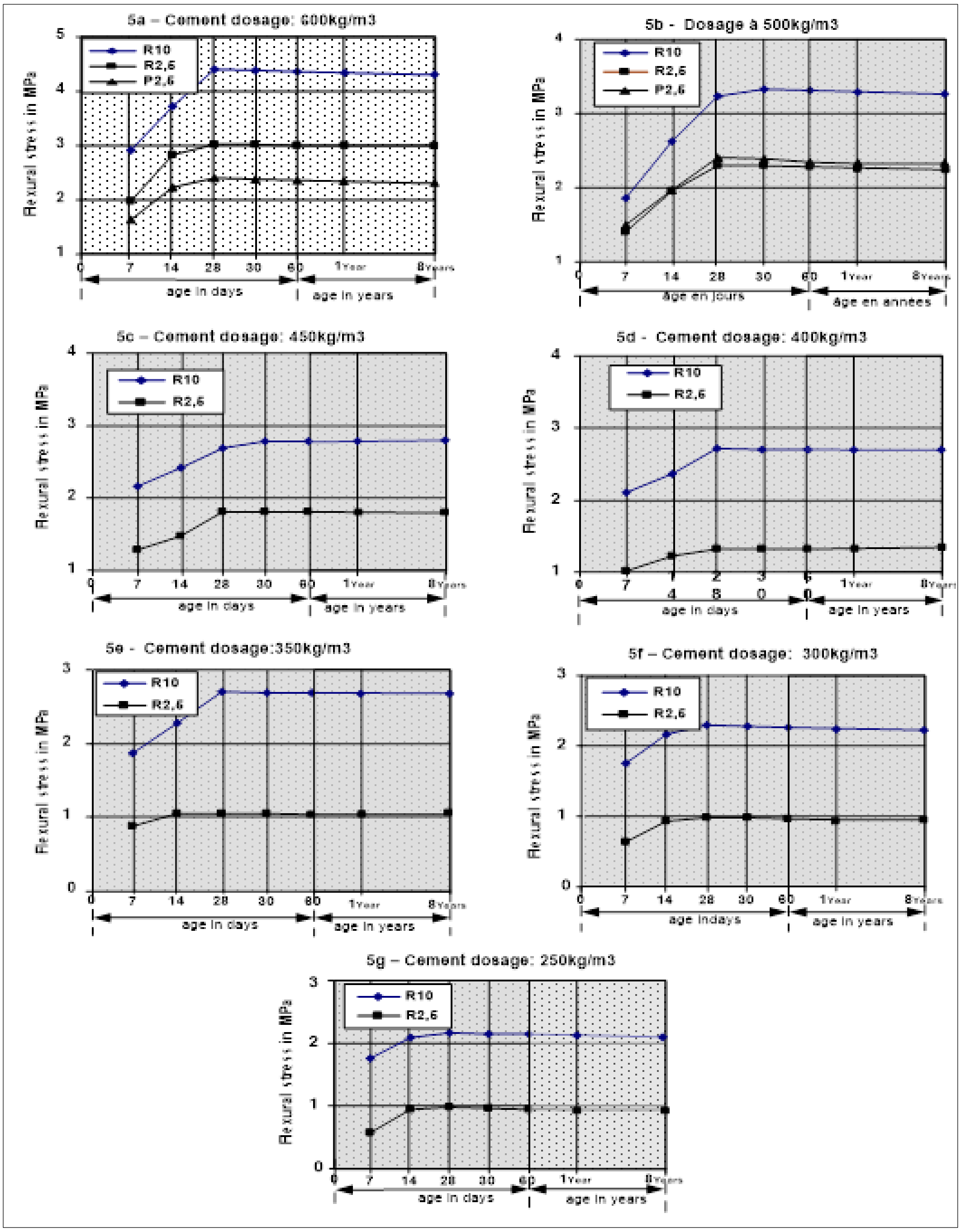


Figure 5 Dry flexural strength according to cement dosage and age

High levels of dry flexion stress ranging between 4,3 MPa and 2,10 MPa for wood concrete produced with R10 class wood shavings could be explained by the fact that their large size might mobilize more friction efforts at the level of binding chips interfaces. This resistance of friction increases up to the 28th day and seems to stabilize even after 8 years.

3.5. Water absorption rate (Figure 6)

Results presenting water absorption rates for 28 days old test tubes obtained for various dosages according to the duration of immersion are summarized in Figure 6.

A look at the evolution of the corresponding curves depending on the length of the immersion period reveals that the highest values of water absorption rates are given by test tubes produced with P2.5 or R2.5 chips, and the lowest by those made with R10 chips, irrespective of dosage or immersion period. Moreover, this water absorption rate decreases as cement dosage increases, and increases during the first 3 days of immersion, before stabilizing beyond this period.

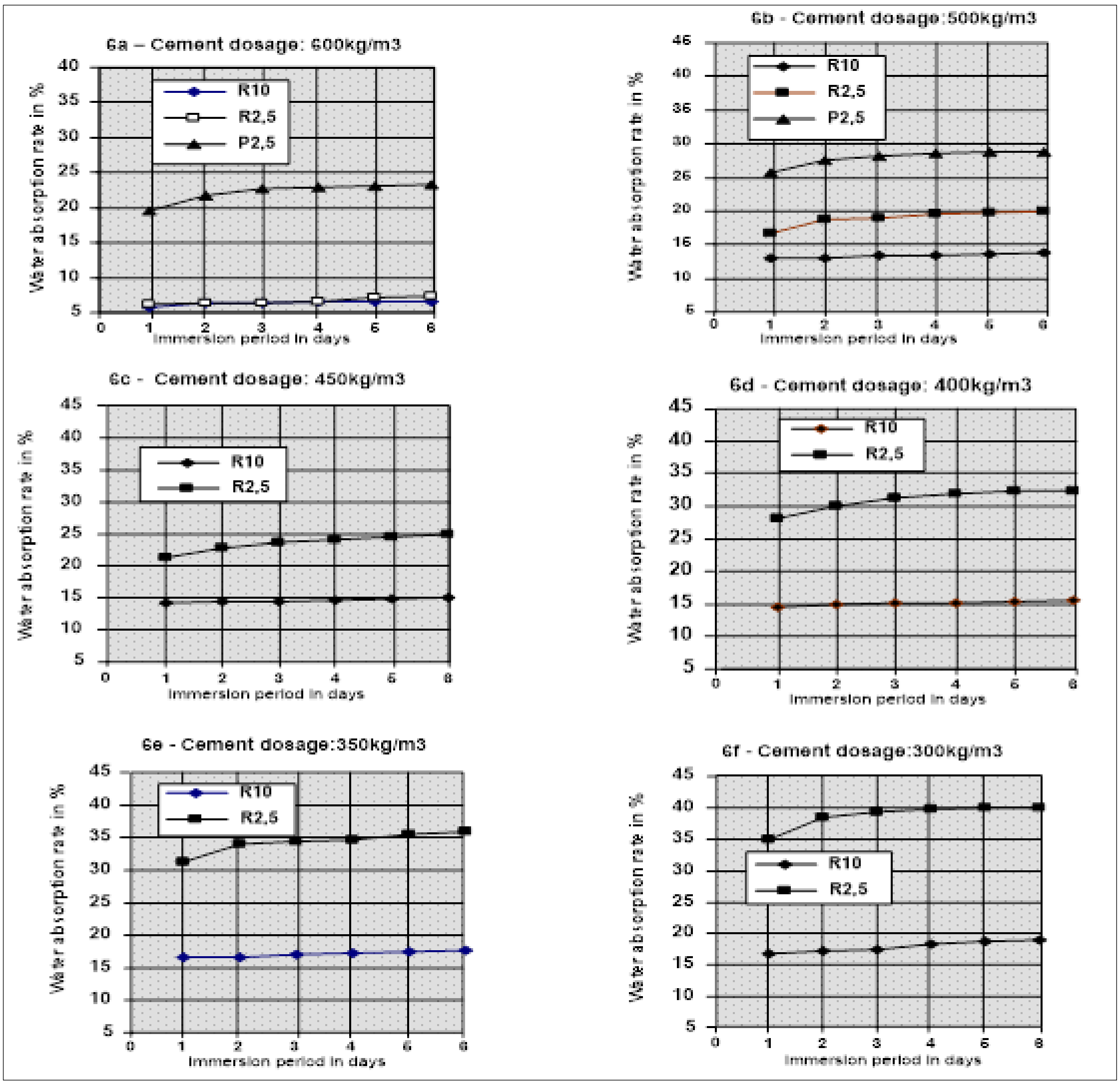


Figure 6 Water absorption rate for 28 days old specimens, according to cement dosage and immersion period

3.6. Wet compressive and flexural strength (Figure 7)

Curves showing the ratio between wet compressive strength to dry compressive strength(or wet flexural strength to dry flexural strength) at 28 days and according to cement dosage show that: irrespective of dosage, this ratio is lower than 1. These results reveal that compressive strength or flexural strength of various wood concrete specimens decreases after they are submerged into water. These ratios vary between 0,88 and 0,65 for compressive strength and between 0,88 and 0,62 for flexural strength. These decreases in values show that these wood concrete specimens are sensitive to water.

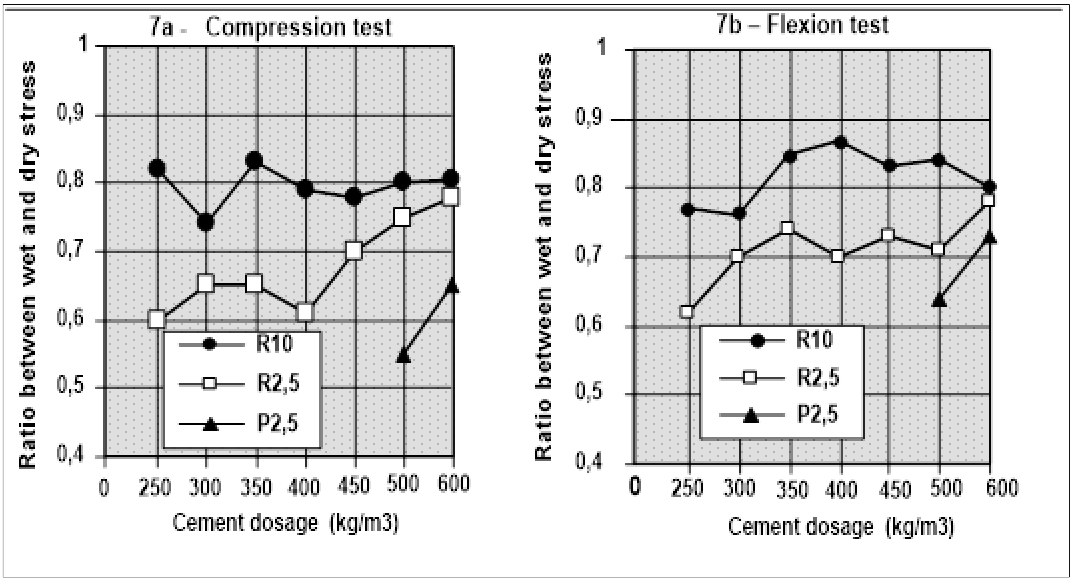
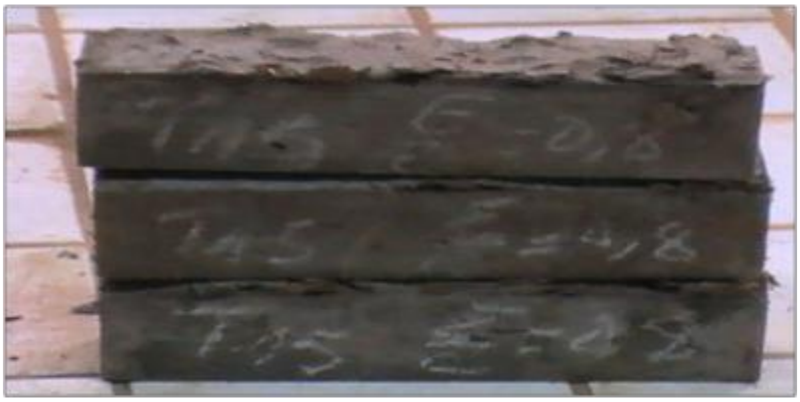


Figure 7 Ratio between wet and dry stress values for 28 days old specimens (after 6 days of immersion) according to cement dosage



Picture 3 Height (8) years old wood concrete test tubes

Picture 4 Height (8) years old wood concrete test tubes after flexion tests

4. Possible uses of wood concrete

This study shows that wood concrete produced from the mixture of cement and wood chips belong to the category of lightweight concrete. This concrete can thus be used for the production of briquettes, wall and floor dressings. Their low density indicates that they can be used as insulation material. Considerable warping observed during tests mean that the use of this material in seismic zones is very interesting for the high quantity of energy it can absorb (R10 or R2.5 wood shavings class). Given the fact that the production of wood concrete with P2.5 chips consumes large quantities of cement, it is advisable to use R2.5 class, especially those of R10 class. However, we pointed out a major shortcoming: the sensitivity of wood concrete to water. This shortcoming can be avoided by taking special measures against moisture where these materials are used or by giving chemical treatment to chips to make them waterproof. Nonetheless, there is a shortcoming that may appear on the long term: the possibility for cement to affect woodfibres. As concerns Bubinga chips used here, we noted that after 8 years of contact with cement, they remained intact (Pictures 3 and 4). From this result, one could say that Bubinga chips will not be affected by cement used for the production of wood concrete.

5. Conclusions

The above study shows that wood concrete produced from the mixture of a given type of cement and Bubinga wood shavings of various classes belong to the category of lightweight concrete. As such, it can be used for building walls, for the floor and for insulation systems, provided that cement dosages are equal or higher than 300 kg/m3. If these materials are to be used in a damp environment, it would be necessary to protect them. Results obtained in this study can be extended to other types of wood chips provided that they receive special treatment that will render them waterproof and resistant to attacks from the type of cement used.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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