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Physical properties of wood cement composites made with Portland cement and some Cameroonian hardwoods particles

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ABSTRACT

The purpose of this work is to physically characterize wood-cement composite materials. The wood species used are Ayous, Movingui, African Padouk and Sapelli. The cement used is Portland cement CPJ35. For that purpose, we made specimens with wood species cited above. Then we carried out the drying and the humidification of these samples and made necessary measurements to characterize these materials physically. We determined most important physical properties of wood (density, the total volume shrinkage and swelling, moisture content and specific gravity) to characterize these materials. It comes out from this study that wood-cement composite materials are lighter than usual building materials such as mortar and concrete. We noted that, of four wood-composite materials elaborated, the sapelli-cement composite is that which presents the best physical properties, in particular the hygroscopic properties.

Introduction

Wood-cement composites are inexpensive materials which can be produced using a relatively simple technology. They are primarily used in the building for nonstructural applications, as interior and exterior sheating, light partitions, tiles, covers, anti-noise and anti-fire barriers. They have interesting properties in particular: lightness, performances acoustic and thermal, fire resistance, resistance to termites and fungus. Also, the increasing cost of resins and machinery necessary for the production of resin-bonded boards is another point in favor of mineral-bonded composites (Ahn and Moslemi 1980; Simatupang and Geimer 1990; Simatupang et al. 1991; Oyagade 1994; Badejo 1999; and Ajayi 2000).

The general public in Cameroun is unaware of the existence and the advantages of these composite materials which play more and more an important role in the development process of several countries. It is a question, through our study, to popularize and promote wood-cement composite materials. For that, we made samples of wood-cement composites with the following species: Ayous, Movingui, African Padouk of and Sapelli. Then we determined their most important physical parameters (density, the volume swelling and hygroscopicity), which we compared to those of concrete and mortar. We used the species cited above because they are easily accessible on the market. We used Portland cement CIMENCAM CPJ 35 because of its major use in the construction industry, and because it is made in Cameroon.

Generalities on wood-cement composites

Wood-cement composites are materials made up of particles or fibres of wood linked by cement. To note that there are also composites containing vegetable sources others that wood, like bamboo, sisal, flax, etc. Although many products already exist on the market, knowledge concerning wood-cement composites remains still limited. There is in particular a problem of compatibility between cement and certain wood species, which cannot thus be developed in this form. Problems of dimensional stability and ageing of the composite exposed to important variations of moisture were also noted.

Dimensional variations

In hardened material, the matrix cement and wood are both porous and hygroscopic. Water forms integral part of material and can be in several forms:

- interstitial water presents in the capillary pores of hydrated cement and in the cellular cavities of wood (lumens);
- adsorbed water, fixed on the absorbent sites of material. In cement, this water is confined in freezing HSC whereas in wood, it is primarily adsorbed on the level of the sites hydroxyls of the lignocellulosic matter;
- constitution water of cement and wood.

The moisture contents free and bond water vary according to the moisture of the environment, which involves phenomena of swelling and shrinkage about 3 to 5 mm/m (Fan and Al, 1999 and 2006; Mougel and Al, 1995; Ledhem and Al, 2000). The width of these dimensional variations depends on the structure of the wood-cement composites. They remain however very low than the variations undergone by wood alone or in association with a resin (particle boards, plywood…).

The majority of the studies planned to reduce the dimensional instability of the wood-cement composites attempted to treat the wood particles. Patented processes, such as processes K-X, AGRESLITH-C, SILWOOD or DURISOL, are currently used in certain industries. These processes employ mineral solutions (silicate of sodium, acid phosphoric, calcium chloride) to mineralize wood. The crystallization of these salts in wood limits the release of extractable indeed and improves at the same time the dimensional stability of the particles of wood and the adhesion between wood and the matrix of cement (Rudkiewicz, 2000; Merkley and Al, 2004).

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Some authors also showed that the incorporation of sand could reduce the number of microscopic cracks generated during the withdrawal, while improving the mechanical performances of composites (Mougel and Al, 1995). In fact, the incorporation of aggregates having a modulus of elasticity higher than that of the cement paste, limit the propagation of the microscopic cracks and improves dimensional stability (Bröker & Simatupang, 1974; Neville, 2000).

Materials And Methods

Here, we present the materials used to make our samples of wood-cement composites and the lab materials that enabled us to determine measurements necessary to characterize these materials physically. And then, we describe the methods adopted for the physical characterization.

Materials

In order to realize our composite materials, we used Portland cement (CPJ 35) made in Cameroon by CIMENCAM, water and four Cameroonian hardwood species : Ayous, Movingui, African Padouk and Sapelli.

Portland cement CPJ 35

CPJ 35 cement is a Portland cement manufactured in Cameroun. It is conceived for the principal needs for current masonry: breeze blocks, coatings, mortar, concretes. Its compressive strength after two days hardening is 15 MPa, and 35 to 39 MPa at 28 days.

Ayous

Ayous is a wood of the class of angiosperms. Its scientific name is *Triplochiton scleroxylon*, and its color of reference is clear yellow.

Movingui

The scientific name of the Movingui is *Distemonanthus benthamianus*. Its color of reference is the yellow.

The African padouk

The scientific name of African Padouk is *Pterocarpus soyauxii Taub* which exists in Central and Western Africa. Its color varies between the red purplish coral and the brown.

Sapelli

The scientific name of the Sapelli is *Entandrophragma cylindricum*. Its color of reference is brown red.

Powders of the following species Ayous, Movingui and Padouk were obtained by means of an electric grinding stone. The particles of sapelli were obtained by sawing of sapelli wood. Figure 1 shows the photographs of the powders of the various species. Figure 2 shows the photographs of the balance which made it possible to measure the weight of the samples, the drying oven which made it possible to dry the samples, the slide caliper which made it possible to measure the dimensions of the samples and the mould in which the samples were formed.

Figure 1: Photographs of the flour and particles of wood species tested.

Figure 2: Photographs of the weighing balance, the drying oven, the slide caliper, and the mould.

Methods

Elaboration of wood-cement composite specimens

For the manufacture of the various samples, we initially mixed the wood particles of each species, water and cement with the following proportion 50% of wood, 30% of cement and 20% of water. We mixed them manually during approximately five minutes. Then we placed the various formed pastes in a wooden mould, by compressing them using a small piece of wood. We found that after of three days of air drying, the samples were not hardened yet. This is why we made new samples by using 50% of cement, 30% of wood powder and 20% of water. After two days of air drying, the samples were removed from the mould.

Physical characterization of the specimens

After having removed the samples the mould, we measured their initial weights. In order to determine the physical properties of the samples, we have carried out the drying and the hydration of the samples to determine their weights and volumes in anhydrous and saturated states.

Drying was carried in the oven mentioned above. The anhydrous weight is obtained by drying at a temperature of 103°C until obtaining a constant weight. After that the hot specimens are removed and put in the lab in order to enable them to reach equilibrium with the lab environment.

The weight of the specimens in a saturated state is obtained by immersion in water until obtaining a constant weight (hygroscopic equilibrium). We dried the samples during 10 hours and hydrated them during 24 hours.

Determination of the density

In the anhydrous state, the density is given by the relation:

$$\rho_0 = \frac{M_0}{V_0}$$

M_0 and V_0 are respectively the weight and the volume of the sample in anhydrous state.

At a moisture content H the density is :

$$d = \frac{M}{\rho_e V}$$

M and V are respectively the weight and the volume of the sample at the moisture content H.

Determination of the moisture content

The moisture content is determined the relation :

$$H(\%) = \frac{M - M_0}{M_0} \text{x } 100$$

Determination of the specific gravity

In the anhydrous state, the specific gravity is given by the relation:

$$G_0 = \frac{M_0}{\rho_e V_0} \cdot$$

At a moisture content H the specific gravity is given by:

$$G = \frac{M_0}{\rho_e V} \cdot$$

Total volume shrinkage

The total volume shrinkage is given by:

$$R_V(\%) = \frac{V_S - V_0}{V_S} \text{ x } 100$$

V_S is the volume of the sample in a saturated state.

V_0 is the volume of the sample in an anhydrous state.

Results And Discussion

Here, we present the composite materials which we made theirs physical characteristics. And then we present the results of drying and humidification. From these results, we plot the curves representing the evolution of the weights during drying and the hydration according to time, the curves representing the moisture content according to time during the hydration, the curves representing gravity specific according to time, and the curves of swelling. This is followed by a discussion of the results obtained. The weights were measured with an uncertainty of 0.1g, and the dimensions were measured with an uncertainty of 1mm.

Presentation of the specimens

Figure 3 below shows the photographs of the samples that we made.

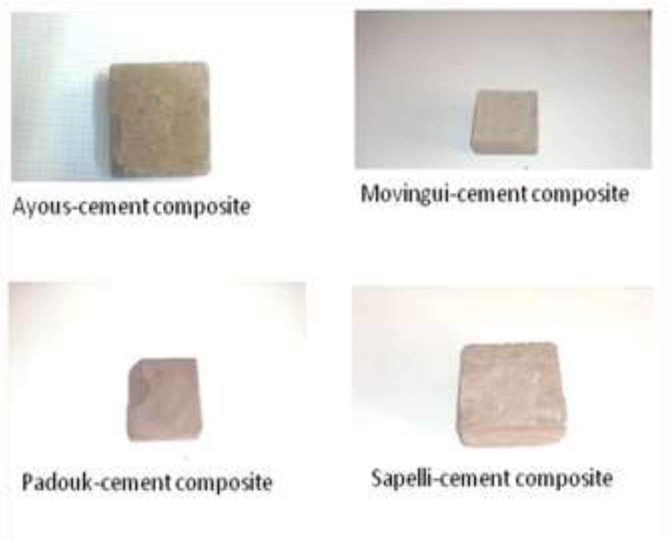

Figure 3: photographs of the samples

During air drying free, we noted that the sapelli-cement composite hardened more quickly than the other composites. The movingui-cement composite came in second position, the ayous-cement composite came in third position. The padouk-cement composite was slowest to harden. This raises the problem of compatibility between each wood species tested and cement. The order of hardening observed could be explained by fact that the compatibility of the sapelli with cement is higher than that of the movingui, which in its turn has a compatibility higher than that of the ayous, then comes the padouk in last position. This is still to be evaluated in other research. The fast hardening of the sapelli can be also explained by the size of particles of sapelli used. These particles are larger than the size of the powder grains of the other species.

The first samples which we manufactured with a proportion in mass of wood powder 50%, cement 40% and water 10% did not harden even after three days of drying to the sun because of the great quantity of lignocellulosic matter contained in the majority quantity of wood powder. This problem can be solved either by adding to the mixture an additive such as calcium chloride CaCl2, magnesium chloride or sulphate Al2(SO4)3 aluminium which makes it possible to accelerate the catch of cement, or while making boil the wood powder to reduce or extract completely the lignocellulosic matter that it contains and which delays the catch of cement.

Interpretation

From the table above, we note that wood-cement composites are lighter than cement and mortar. This is due to the fact that wood is less dense than cement and sand. Consequently the wood-cement composites are less hard than cement and the mortar. We note that the volume shrinkages of composite materials tested are much higher than those of cement and the mortar, just as their maximum moisture contents, except for the sapelli-cement composite, which has a maximum moisture content slightly lower than that of mortar. The total volume shrinkage of sapelli alone is 13.00%. When one associates it with cement, the total volume shrinkage of the material obtained is 9.21%; this shows that it is preferable to use sapelli as a wood-cement composite, for cement makes it possible to improve its dimensional stability. As regards the movingui-cement composite, one notes that its total volume shrinkage is the highest of all the samples tested. This is due to its very great porosity, which causes an important variation of its volume during the hydration.

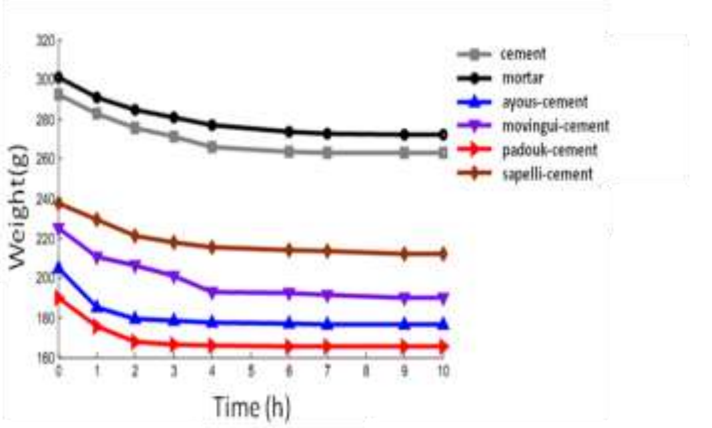

Figure 4 : Evolution of the weights according to time during drying.

Interpretation

We can note that the curves have the same pace. The curves of cement, the mortar and the sapelli-cement composite are practically identical. This is explained by the fact why they appreciably lose their water with same speed. At the end of the fourth hour, the weights of the ayous-cement and padouk-cement composites are practically stable. The ayous and padouk based composites lose the major part of their water at the end of two hours, while cement, mortar, the movingui-cement and sapelli-cement composites lose their water at the end of four hours. This is explained by the fact why the ayous and padouk based composites are the least dense samples. We can deduce that the denser is the sample, the less quickly it dries.

Physical characteristics

Table 1: Physical characteristics of composite materials

Specimen	Density at 15% Moisture Content	Anhydrous Specific Gravity G_0	Total Volume Swelling R_v(%)	Initial Moisture Content H_i(%)	Final Moisture Content H_f(%)
Cement	1.92	1.69	3.68	11.17	19.00
Mortar	1.97	1.76	3.50	10.47	17.30
Ayous-cement	1.49	1.40	8.23	16.21	29.76
Movingui-cement	1.62	1.60	21.01	18.24	30.81
Padouk-cement	1.35	1.25	8.31	14.94	32.36
Sapelli-cement	1.61	1.54	9.21	11.93	17.26

Results of drying

Table 2: Evolution of the weights and volumes of the samples during drying

Time (h)		0	1	2	3	4	6	7	9	10
Cement	masse (g)	292.5	282.8	275.7	271.2	266.1	263.5	263.1	263.1	263.1
	volume (cm^3)	161.64	159.89	158.87	157.92	157.41	156.47	155.96	155.74	155.74
Mortar	masse (g)	300.8	290.2	284.8	280.8	277.1	273.6	272.5	272.3	272.3
	volume (cm^3)	159.40	156.39	155.94	155.23	154.73	154.73	154.52	154.29	154.29
Ayous-cement	masse (g)	205.0	185.3	179.3	178.5	177.5	177.2	176.5	176.4	176.4
	volume (cm^3)	137.69	135.72	132.44	130.92	129.97	127.71	127.23	126.22	126.22
Movingui-cement	masse (g)	224.9	210.9	206.4	201.2	192.7	192.4	191.6	190.2	190.2
	volume (cm^3)	143.06	141.35	140.64	137.65	136.68	136.28	134.60	118.46	118.46
Padouk-cement	masse (g)	190.0	175.8	167.9	166.6	166.1	165.7	165.3	165.3	165.3
	volume (cm^3)	140.05	139.62	137.98	135.24	134.08	133.70	131.97	131.97	131.97
Sapelli-cement	masse (g)	237.4	229.4	221.3	218.1	215.3	213.9	213.6	212.1	212.1
	volume (cm^3)	149.69	145.15	145.62	143.71	143.53	142.11	138.66	137.97	137.97

Results of the hydration

Evolution of the weights according to time

Table 3: Evolution of the weights and volumes according to time

Time (h)		0.25	0.75	1.75	2.75	5	10	15	24
Cement	weight (g)	305.0	310.1	310.5	310.7	311.7	312.5	313.0	313.1
	volume (cm^3)	158.37	161.02	161.25	161.47	161.47	161.47	161.70	161.70
Mortar	weight (g)	307.2	312.3	316.3	316.9	317.5	318.9	319.2	319.4
	volume (cm^3)	156.44	158.55	158.78	159.67	159.67	159.67	159.89	159.89
Ayous-cement	weight (g)	214.7	223..6	227.1	228.5	228.6	228.6	228.9	228.9
	volume (cm^3)	135.53	135.63	136.21	137.66	137.86	138.05	138.64	138.64
Movingui-cement	weight (g)	228.6	240.0	245.2	245.5	246.1	247.8	248.2	248.2
	volume (cm^3)	140.15	145.36	146.99	147.61	148.32	149.25	149.97	149.97
Padouk-cement	weight (g)	207.6	214.7	216.2	216.9	217.2	218.5	218.8	218.8
	volume (cm^3)	140.24	141.92	142.72	143.53	143.72	143.93	143.93	143.93
Sapelli-cement	weight (g)	231.8	237.8	239.1	243.0	244.2	246.7	248.7	248.7
	volume (cm^3)	149.81	150.59	150.73	150.75	151.26	151.47	151.98	151.98

Evolution of the moisture content according to time

Table 4: Moisture content (H) according to time.

Time (h)	0.25	0.75	1.75	2.75	5	10	15	24
H(%) cement	15.92	17.86	18.01	18.09	18.24	18.78	18.97	19.00
H(%) mortar	12.82	14.67	16.16	16.38	16.60	17.11	17.22	17.30
H(%) Ayous-Cement	21.71	26.76	28.74	29.53	29.59	29.59	29.76	29.76
H(%) Movingui-Cement	21.77	26.18	28.92	29.07	29.39	30.28	30.81	30.81
H(%) Padouk-Cement	25.59	29.88	30.79	31.21	31.40	32.18	32.36	32.36
H(%) Sapelli-Cement	9.28	12.12	12.73	14.57	15.13	16.31	17.26	17.26

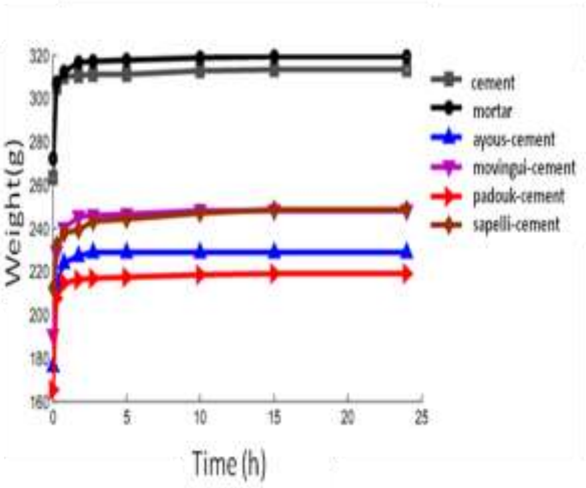

Figure 5 : Evolution of the weights according to time during hydration.

Interpretation

We can notice that all the curves have the same pace. The weights of all the samples, increase considerably during the first five hours. Between five hours and fifteen hours, these weights increase very slightly, and are stabilized from the fifteenth hour.

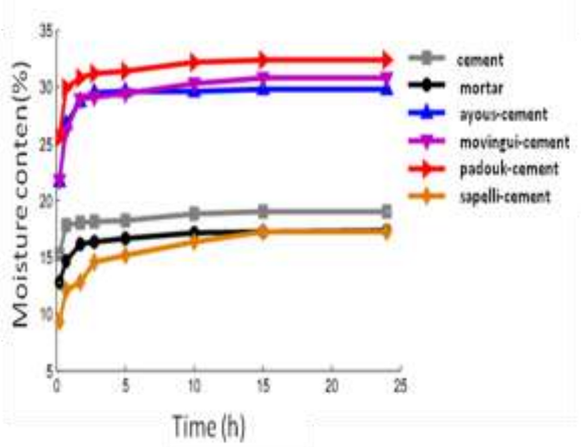

Figure 6: Evolution of the moisture content according to time.

Interpretation

We can notice that padouk-cement has the great maximum moisture content, contrary to the sapelli-cement composite which has the lowest maximum moisture content. This is explained by the fact that the padouk-cement composite is more porous than all the other samples.

The maximum moisture content of the padouk-cement composite is appreciably equal to that of the mortar (17.26% for the padouk-cement composite and 17.30% for mortar), however the point of fibres saturation of sapelli is 29%. This is explained by the fact that, when cement hardens the fibres of sapelli, a great quantity of pores of fibres are stopped, thus reducing the permeability of the composite.

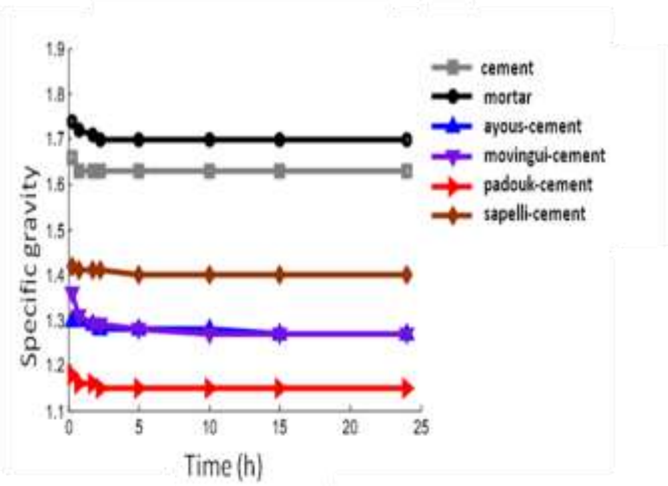

Figure 7 : Specific gravity according to time.

Interpretation

By observing the curves above, we can notice that the specific gravity of cement, mortar, and the composites based on ayous, movingui and sapelli vary very little. This is due to the weak variation of their volumes in the course of time. Zhou and Kamdem (2002) reported that the addition of low-density wood appears to be an important factor that may influence the development of wood-cement composite panels by reducing their overall density. At the end of three hours, the specific gravity of the movingui-cement composite varies considerably. These remarks enable us to conclude that the hardness of the composites based on ayous, padouk and sapelli decreases very slightly compared to that of the movingui-cement composite during the hydration.

Evolution of the specific gravity according to time

Tableau 5: Specific gravity (G) according to time.

Time (h)	0.25	0.75	1.75	2.75	5	10	15	24
G_{ciment}	1.66	1.63	1.63	1.63	1.63	1.63	1.63	1.63
$G_{mortier}$	1.74	1.72	1.71	1.70	1.70	1.70	1.70	1.70
G_{A-C}	1.30	1.30	1.29	1.28	1.28	1.28	1.27	1.27
G_{M-C}	1.36	1.31	1.29	1.29	1.28	1.27	1.27	1.27
G_{P-C}	1.18	1.16	1.16	1.15	1.15	1.15	1.15	1.15
G_{S-P}	1.42	1.41	1.41	1.41	1.40	1.40	1.40	1.40

Evolution of the swelling according to time

Tableau 6 : Swelling according to time

Time (h)	0	0.25	0.75	1.75	2.75	5	10	15	24
$V_{ciment}(cm^3)$	155.74	158.37	161.02	161.25	161.47	161.47	161.47	161.70	161.70
$V_{mortier}(cm^3)$	154.29	156.44	158.55	158.78	159.67	159.67	159.67	159.89	159.89
V_{A-C} (cm^3)	127.23	135.53	135.63	136.21	137.66	137.86	138.05	138.64	138.64
V_{M-C} (cm^3)	118.46	140.15	145.36	146.99	147.61	148.32	149.25	149.97	149.97
V_{P-C} (cm^3)	131.97	140.24	141.92	142.72	143.52	143.72	143.93	143.93	143.93
V_{S-P} (cm^3)	137.97	149.81	150.59	150.73	150.75	151.26	151.47	151.98	151.98

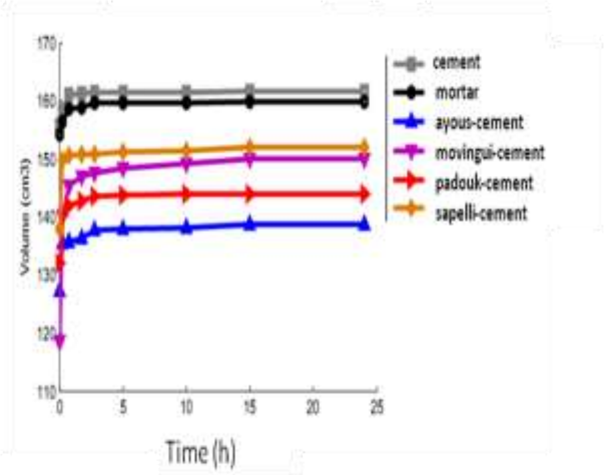

Figure 8 : Swelling according to time.

Interpretation

We can notice that the samples swell very quickly during the first three hours. Between five hours and fifteen hours they swell very slightly. From the fifteenth hour, the samples are completely saturated, volumes remain constant. It is noted that the movingui-cement composite has the greatest rate of increase in volume; it is what explains its greater total volume shrinkage compared to the other samples. We also notice that volumes of the composites based on ayous, padouk and sapelli do not increase enormously like that of the movingui-cement composite. It is what explains their shrinkage lower than that of the movingui-cement composite.

Conclusion

It was a question in this work, to work out and characterize physically wood-cement composite materials. For this study, we chose the following Cameroonian hardwood species: Ayous, Movingui, Padouk of Africa and Sapelli. We realized during the development of the samples, that difficulties of compatibility can arise. The one we faced was due to the inadequate proportions of the various components of the mixture. We proposed curing solutions in certain cases, with these problems of compatibility. After the development of our samples, we have to carry out the drying and the humidification of these materials to determine the sizes necessary to characterize them.

The results obtained revealed us that they are less dense than hardened cement and mortar, and consequently they are lighter. This is why these materials are less expensive than conventional cementing materials. We noted that the majority of these materials are more absorbent than hardened cement and the mortar, but has the advantage of drying more quickly. In the case of sapelli-cement composite, we noticed that it absorbs less water than the other composites. Consequently, it is dimensionally more stable than the other composites. We have also noted that just like cement and mortar, and in spite of their lightness, the wood-cement composite materials preserve practically their hardness during humidification; what makes them more resistant to the rot, insects and fire compared to simple wood. It comes out from this study that the geometry of the wood flour or wood particles, and the lignocellulosic quantity of matter contained in wood have an influence on the physical properties of wood-cement composite materials. The larger the size of the powder grains or wood fibres is, the more the physical characteristics of composite material are better. The more the lignocellulosic quantity of matter is raised, the more the physical characteristics decrease. If this quantity is very important in wood, there is incompatibility between wood and cement, and the composite cannot be formed. In further research we will mechanically characterize our wood-cement composites in order to evaluate their mechanical properties.

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