

The use of wood particles in cementitious materials in order to make them more sustainable as greenhouse gas emissions

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Abstract—Cement building materials are quite aggressive to the environment because of their manufacture causing large amounts of greenhouse gas (GHG) emissions, such as cement and steel. Wood-based materials are great in this respect, as they generally consume less energy for their production and wood stocks carbon in their structure, neutralizing CO₂ emissions, the main GHG. But for various reasons, it is not always possible to apply purely wood materials. This work shows two cementitious building materials, concrete blocks and closing panels, which were developed in researches at the Federal University of Paraná (UFPR - Brazil), which contains wood particles in its composition. These materials, in substitution of the corresponding traditional materials, mitigate GHG emissions by the construction works, without causing technical losses. The materials developed in the cited researches are produced with Portland cement, lime and wood particles. The carbon fixed by the wood plus the CO₂ absorbed from the air by the carbonation of the lime during the first years of useful life neutralizes the majority of the GHG emissions of its production.

Keywords— Construction materials, Greenhouse gases emissions, Concrete blocks, Closing panels.

I. INTRODUCTION

Within this context, many developed countries (or individual cities) have shown concerns about the emissions of greenhouse gases (GHG) generated by the production of buildings, because of the growing environmental challenges facing society nowadays. The problem of the greenhouse effect and the increase of CO₂ concentrations in the atmosphere are becoming increasingly relevant.

Countries in Europe, USA, Australia and Canada have been implementing regulations specifically designed to control buildings' carbon emissions, both for their use time and for their construction time. The current challenge for the construction industry in these nations is to achieve the goal of producing "carbon neutral" buildings from 2020, which means achieving a balance between the quantities of carbon emitted and sequestered or stored. Brazil, although it has not yet reached this level of actions, have concerned about this problem and have taken some actions to minimize their emissions.

In 2008 Nemry et al. published an article under the Joint Research Center (JRC) that presented recommendations for new constructions. The article emphasizing that significant environmental improvement can only be achieved by replacing "conventional" construction products (concrete, steel, bricks, etc.) by wood products. Wood products usually causes less GHG emissions by their production process than other materials and can work as a complement to the forest after the wood was harvested, storing the carbon during its useful life (Hetsch 2008).

It should be noted that from 40 to 45% of the wood mass is composed of carbon and since this element represents only a fraction of the CO₂ molecule, therefore each unit of carbon mass fixed in the wood represents the non-emission of 3.67 mass units of CO₂ (Oliveira et al. 2011).

This work shows that some conventional constructions material can be replaced by wood-based materials, which are more environmentally friendly in the context of GHG emissions. The wood products emit less GHG for their

production, besides storing carbon in their structure, minimizing the balance of emissions to the atmosphere.

The stored carbon neutralizes part of the CO₂ emissions resulting from the construction of the works and in the developed countries, following the recommendations of the international standards ISO 14025:2006, ISO 14040:2006 and ISO 14.044:2006. The UN Intergovernmental Panel on Climate Change (IPCC) allows for the accounting of carbon stored in wood products of certified origin, but not carbon of fossil origin, as recommended by ISO 14.044:2006.

The major building materials such as steel and Portland cement emit large amounts of GHG for their production. It is because of the consumption of fossil fuels and the treatment of raw materials. For example, the Portland cement manufacture is responsible for approximately 7% of the world's CO₂ emissions. It occurs because of the decarbonation of limestone and consumption of fossil fuels (Mehta 2001).

The substitution of the usual materials, which are great cause of emissions of GHG, by other wood-based materials allows significant reductions in GHG emissions. It is important to note that wood particles can be used in the composition of mortars and concrete used in the manufacture of various pre-cast construction products. The proper use of these particles enables reductions in the consumption of cement and aggregates, making the products lighter and environmentally friendly from the point of view of GHG emissions.

Within this context, two wood-based building materials are being developed at the Federal University of Paraná (UFPR) in Brazil: a cementitious block for walls and a cement panel for closures. Both are characterized to have in their composition wood particles replacing the aggregates and minimizing the consumption of Portland cement. As they contain significant amounts of wood in its composition, the carbon stored neutralizes great part of GHG emissions from its production. The wood particles were immersed in a water lime suspension to prevent the wood extractives liberation. These extractives change negatively the important hydration reactions in the cementitious composition. The hardening of the lime also captures CO₂ from the air collaborating with wood particles in the function of carbon storage.

The objective of this work is to show two alternatives of cementitious building materials, a block and a closing panel, which are more environmentally friendly from the point of view of GHG emissions, which can replace traditional materials that are widely used. The use of these blocks and panels can become interesting alternatives to

achieve the target of 2030 of to built "carbon neutral" buildings.

1.1. THE CEMENTITIOUS MATERIALS WITH WOOD PARTICLES

The first wood-based building material is a cementitious block with wood particles developed by Villas Bôas experimentally produced in UFPR (Villas Bôas 2016). The block contains *Pinus spp* particles with dimensions between 4.75 mm and 2.36 mm sieve. The block is hollow and has the external dimensions of 14x19x39 cm and it has adequate mechanical characteristics for non-structural walls. Figure 1 shows the block details.



Fig. 1: The cementitious block with wood particles (Villas Bôas, 2016).

The materials used for the block production, in addition to the wood particles, is Brazilian Portland cement type CP II-Z, lime (CV) and water. In the beginning of the production, the wood particles are submitted for a pre-treatment in a water lime suspension. This action removes the possible inhibitory effects from the extractives of the wood to the hardening reactions of Portland cement (Parchen et al. 2015).

In the sequence the cement is added with water (water/cement ratio 0.20) to the suspension of lime already mixed with the wood particles. The mixture was mixed in a horizontal mixer. The blocks were molded and compacted in an automatic industrial hydraulic vibro-press, usable for the production of concrete blocks.

The hardened density of the blocks has mass around 4.645 kg. The material consumption per block for its production was: 2.264 kg of Portland cement; 1.184 kg of *Pinus spp* particles; 0.2652 kg of lime and 1.372 kg of water. The block has approximately 25.5% of its mass in wood particles of *Pinus spp*.

It is important to emphasize that the addition of wood particles decreases the weight of the block and improves their thermal insulation properties. Similar conventional concrete blocks similar are traditionally used in civil construction for erecting non-structural walls, are produced with common aggregates of sand or crushed rock and has a mass of approximately 10 kg.

The second material is a cementitious closing panel produced with a mixture of Portland cement, lime and wood particles. The panel was developed and experimentally produced in UFPR in a research project by Parchen (2012). The panel has 25 mm of thickness and adequate mechanical characteristics for use in internal walls. The mass content of wood particles (*Pinus spp*) is 37%. Figure 2 shows the panel in a bending test.



Fig. 2: The cementitious closing panel with wood particles in a bending test (Parchen 2012).

The materials used in the panels were, the wood particles, Brazilian Portland cement type CP II-Z, lime (CV) and water. For the same reasons, the wood particles are pre-treated with lime and water reaching a final water/cement ratio of 0.33. The mixture was made in a mixer. The molding and compacting of the panels were done in a concrete vibrating table. The material consumption per production of m² of panel is: 8.750 kg of Portland cement; 7.875 kg of *Pinus spp.* particles; 1.425 kg of lime and 2.855 kg of water. The weight of this panel is 18.5 kg/m². Conventional cementitious panels weigh varies from 14 to 43 kg/m², depending of their thickness and density. The presence of the wood particles and the increased thickness has the vantage to provide better thermal insulation to the panel. Figure 3 shows the cementitious closing panel in a thermal insulation test.

The addition of the wood particles in the blocks and panels provides improvements in characteristics such as thermal insulation and weight, but due to the cost of

implementing the production, its initial costs should be 20% greater than the traditional options.



Fig. 3: The cementitious closing panel in a thermal insulation test (Parchen, 2012).

II. MATERIAL AND METHODS

With the purpose of evaluating the environmental performance, more specifically CO₂ emissions and carbon storage of the cementitious block and panel with wood particles; it was carried a comparative analysis with some similar products commercially produced. These products have not produced industrially yet, because of that it was not possible to develop a LCA, but it was feasible to estimate the CO₂ emissions caused by their production.

The comparative analysis was done firstly by raising the CO₂ emissions by the production, the storage and the capture of carbon by researched products. The emissions were calculated through the sum of the emissions of raw materials, the estimated emissions by the transport of these to an industrial unit and the emissions by the process of manufacturing. The intention was simulate a LCA for considering the limits of "cradle-to-gate".

The calculation of the carbon stored in the mass of the products was estimated based on the amount of wood and the carbon content of the wood. In addition to the carbon storage, the researched products contain lime in their composition. The lime captures CO₂ from the air (carbonation process) during its hardening process.

In order to set up the information base for the comparisons of the products with other similar industrialists, were raised the amounts of CO₂ emissions by the production of several ones manufactured commercially in Brazil and abroad. The information for the comparison of emissions with Brazilian products was taken from LCA or from industrial emission survey procedures. The international industrial products were based on some

European and North American industries publish the Environmental Product Declaration (EPD). An EPD is a document based on ISO 14025/2006 and ISO/TS 14067/2013.

2.1. THE EMISSIONS CAUSED BY THE RAW MATERIALS OF THE PRODUCTS

The most important raw material for the production of cement matrix blocks and panels in terms of CO₂ emissions is Portland cement.

To obtain the EF of Portland cement was considered a LCA developed in Brazil for concrete blocks CBCS (2014), in which the EF of Portland cement was based on the average value for the production of one ton in five years, 2008 to 2012, published by the WBCSD (2013). The EF for CP II-Z cement was estimated from 0.600 to 0.804 kgCO₂e/kg, with an average of 0.702 kgCO₂e/kg. To the estimatives of this article, the last value was used.

To obtain the EF of the lime, the production systems of the local industries of this material were analyzed. The lime is produced in kilns at temperatures of 700 to 1000°C. Carbon dioxide emissions mainly occur in the extraction of the carbon of the limestone and burning the fuel. The EF of the lime depends on the temperature and the residence time in the furnace. In order to estimate lime EF and emissions by the mixture work, was used the conservative EF estimated by Costa (2012), which is 1.184 kgCO₂/kg. This value was the EF used by the lime industries close to City of Rio de Janeiro (similar conditions to the Region of UFPR, Curitiba, Brazil).

For the production of the wood particles only the emissions from the consumption of electric energy were considered. It was considered that because the wood particle industries uses thermal energy from the burning of biomass of certified origin, residues of the industry itself, as Hetsch (2008) recommends. The emissions from the electric energy used in the process were based on Costa (2012), with the EF for this step being considered at 0.0600 kgCO₂/kg of particles.

The transport emissions of the raw materials from their place of production to the production facility were estimated, considering a distance of 50 km. Simulating transport using semi-heavy trucks, using the Diesel consumption factor of 0.196 L/t/km of Costa (2012), and the EF of 3.3 kgCO₂/L of Diesel also used in CBCS (2014), we reached an EF for transport each cement block with 0.0150 kgCO₂/block.

For the production of the researched block, the emissions by the mixture and the vibro-densification work, was based on the emissions calculated for the LCA of

concrete blocks CBCS (2014). With this information was estimated EF in 0.030 kgCO₂/block. For the production of the panel, considering the mixture, the densification and the molding, this work also based on the emissions resulting from the electric energy calculated in Costa (2012), estimated the EF for this step the value of 0.00006 kgCO₂/kg. The table 1 shows the CO₂ emission factors of raw materials used and energy sources.

Table 1 Emission factors and sources of the information.

Input	Emission factor (EF)	Source
Diesel	3.3 kgCO ₂ eq/L	CBCS (2014) apud Wang et al. (2004)
Electricity	0.06 kgCO ₂ eq/kWh	MCTI (2013) – avg. of years 2011/12/13
Cement CP II-Z	0.702 kgCO ₂ eq/kg	WSBD (2013)
Lime	1.184 kgCO ₂ /kg	Costa (2012)
Wood particles	0.06 kgCO ₂ /kg	Costa (2012)

2.2. THE CO₂ UPTAKE IN THE WOOD AND IN THE LIME

For the calculation of the carbon stored by the wood, is necessary knows the mass quantity of the wood particles and the carbon content for the species used were used. In Oliveira et al. (2011), the carbon content (T_c) was found for *Pinus spp.*, with T_c being 0.41. The lime absorbs CO₂ from the air during its hardening process, when the calcium and magnesium hydroxides are converted into carbonates.

Equation (1) allows to estimate the total mass of CO₂ that can be absorbed by the lime. The equation estimates the masses of CO₂ that are absorbed by the hydroxides of calcium and magnesium present.

$$C = CL \cdot (F_{CaO} \cdot M_{CO_2} / M_{CaO} + F_{MgO} \cdot M_{CO_2} / M_{MgO}) \text{ kg/block (1)}$$

At where:

CL = Consumption of lime;

F_{CaO} = The CaO mass fraction in the lime;

F_{MgO} = The MgO mass fraction in the lime;

M = Molar weight of oxides

(CaO=56, MgO=40 and CO₂=44);

Therefore:

$$M_{CO_2} / M_{CaO} = 44/56 \text{ e } M_{CO_2} / M_{MgO} = 44/40$$

The considered values for the CaO and MgO oxide masses for lime were 63.9% and 30.8%, respectively (Mattana,2013).

The potential masses of CO₂ uptake by lime were estimated considering 92% of the total potential, which is the value generally used in LCA, as mentioned in Eleni et al. (2014). For the lime the absorption or sequestration potential was calculated based on the average values of the percentages of oxides obtained by Mattana (2013) for lime already hydrated, disregarding the masses of water present.

III. THE RESULTS CARBON EMISSIONS AND UPTAKE

The next sub-items show the calculations of emissions and carbon uptake for the cement block and cementitious panel with wood fibers.

3.1 THE CEMENT BLOCK WITH WOOD FIBERS

With the consumption of the materials and services, as well as the EF selected, the calculation was carried out to simulate the production emissions of the researched block. The table 2 presents the raw material emissions and the production steps; at the end it shows the EF per block (14x19x39cm).

Table 2 Raw and production emissions per block.

Block	Consume per block	EF kgCO ₂ /kg	Emissions kgCO ₂	%
Cement CP II Z	2.264 kg	0.7021	1.5896	78.7
Lime	0.265 kg	1.1840	0.3140	15.5
<i>Pinus</i> spp partic.	1.184 kg	0.0600	0.0710	3.5
Water	1.372 kg	-	-	-
Raw transport	1 unit	0.0150	0.0150	0.7
Product. Proces.	1 unit	0.0300	0.0300	1.5
Emission Factor per block (kgCO ₂):			2,0196	100

The CO₂ uptake or stored in the wood was obtained using the Tc value of 0.41 and the consume 1.184 kg of wood particles per block, was obtained the total carbon stored of 0.485 kg of carbon per block. Therefore this carbon storage represents the non-emission, or neutralization of 1.780 kgCO₂ per block. It is important to note that the storage period will be the life of the wall, this means practically the same period of life of the building.

The CO₂ uptake by the lime was obtained using equation (1), that allows to estimate the total mass of CO₂ that can be absorbed by the lime. With the equation this work estimates the masses of CO₂ that are absorbed by the hydroxides of calcium and magnesium in 0.208 kgCO₂.

The values of the emissions, uptake or storage and carbon balance for the block are presented in table 3. It can

be observed in these numbers that the carbon stored by the wood particles represents approximately 90% of the total.

Table 3 CO₂ uptake and emissions per block.

CO ₂ uptake and emissions	kg.CO ₂
Total CO ₂ emissions by raw and production	2.020
CO ₂ uptake by wood particles (25.5 % of total mass)	1.780
CO ₂ uptake by lime	0.208
Balance (CO ₂ emissions - CO ₂ uptake)	0.031

For comparisons with some commercially produced blocks, this work has raised production emissions and carbon storage by some blocks of characteristics and similar to the one studied in this work. For international products the information has been withdrawn, EPD published by manufacturers.

To allow comparison between blocks, in the table 4 are presented some physical characteristics (weight, volume and dimensions) and emissions per block (in CO₂ equivalent or CO₂e).

For comparison to block B, that is massive and in Imperial measures system, its dimensions had to be adjusted to the same ones of the Brazilian blocks. This was possible because in its EPD the emissions are by weight, as well as by blocks. The same was not possible for the international blocs (B and C), which were slightly higher than the others.

Observing the net emissions of the blocks, it is verified that the UFPR block, due to its content of wood fibers, emits very few carbon than the commercial ones.

Table 4 Carbon net emissions by various blocks

Prod.	Block		KgCO ₂ e emissions		
	Weight (kg)	Dim. (cm)	Blk.	Kg	wall m ²
Rch	4.64	14-19-39	0.03	0.007	0.39
A	13.97	15-19-39	3.35	0.240	41.88
B	4.49	14-19-39	1.99	0.442	24.83
C	10.43	15.2-20.3-40.6	1.61	0.154	18.17
D	12.00	14-19-39	2.81	0.234	35.15
E	10.25	14-19-39	0.60	0.063	8.12

Legend:

Rch is the researched block.

- A) Czech Rep., a structural concrete block (KB-BLOK 2009);
- B) Europe, a lightweight aerated concrete block (Ruuska 2013);
- C) USA (California), a structural concrete block (ANGELUS 2013);
- D) Brazil, a non-structural concrete block (QUANTIS 2012);
- E) Brazil, a structural concrete block (CBCS 2014).

3.2 THE CEMENTICEOUS PANEL WITH WOOD FIBERS

To the panel (25 mm thick), with the consumption of the materials and services, as well as the EF selected, the calculation was carried out to simulate the production emissions of the researched panel. The table 5 presents the raw material emissions and the production steps, at the end it shows the CO₂ emission factor per m² of panel.

Table 5 Raw and production emissions per m² of panel (25 mm thick).

Raw material	Consum per m ²	EF r kgCO ₂ /kg	Emissions kgCO ₂ /m ²	%
Cement CP II Z	8,750	0.702	6.143	66.5
Lime	1,425	1.184	1,687	18.3
<i>Pinus</i> spp particles	7,875	0.060	0.472	5.1
Water	2,855	-	-	0.0
Raw transport	1 unit	0.015	0.314	3.4
Product. process	1 unit	0.030	0.627	6.8
Emission factor per m ² (kgCO ₂):				100

The CO₂ uptake or stored in the wood was obtained using the Tc value of 0.41 and the consume 7.875 kg of wood particles per m² of panel, was obtained the total carbon stored of 3.23 kg of carbon per m² of panel. Therefore this carbon storage represents the non-emission, or neutralization of 11.84 kgCO₂ per m² of panel.

The CO₂ uptake by the lime was used the equation (1) to estimates the masses of CO₂ that are absorbed by the hydroxides of calcium and magnesium was calculated an uptake of 1.118 kgCO₂ per m² of panel.

The values of the emissions, uptake or storage and carbon balance for the panel are presented in table 6. It can be observed in these numbers that the carbon stored by the wood particles represents approximately 91% of the total.

Table 6 CO₂ uptake and emissions per m² of panel.

CO ₂ uptake and emissions per m ²	kg.CO ₂
Total CO ₂ emissions by production	9.24
CO ₂ uptake by wood particles (37.7 % of total mass)	11.84
CO ₂ uptake by lime	1.12
Balance (CO ₂ emissions - CO ₂ uptake)	-3.71

For comparisons with some commercially produced panels, this work has raised production emissions and carbon storage by some panels of characteristics and similar to the one of the UFPR research. For international products the information has been withdrawn, EPD published by manufacturers.

To allow comparison between the panels, in the table 7 are presented some physical characteristics (density and thickness), their percentage of mass of cellulose or wood fiber, emissions and carbon uptake per m² of panel (in CO₂ equivalent or CO₂e).

Table 7 Carbon emissions and uptake by various panels.

Product	Panel			Emissions		
	Thick (mm)	Density (kg/m ³)	Cellulose or wood %	Product (kgCO ₂ e / m ²)	Uptake (kgCO ₂ / m ²)	Net (kgCO ₂ / m ²)
Rch	25	0.74–0.65	37.7	9.24	12.95	-3.71
E	24	≥1.65–1.80	23.0	35.81	17.84	17.97
F	16	1.39	8.0	12.61	2.88	9.73
G	8	1.58	0	8.08	-	8.08
H	12.5	1.15	0	5.13	-	5.13
I	10	≥170	10.0	12.31	2.00	10.30

Legend:

Rch is the researched panel.

E) Germany, a panel produced with cement and wood fibers (Bossenmayer, 2008);

F) Malaysia, a panel produced of fibrocement with cellulose (Bossenmayer, 2014);

G) Belgium, a panel produced with cement and expanded shale (Bossenmayer, 2013a);

H) Germany, a panel produced of fibrocement (Bossenmayer, 2013b);

I) Denmark, a panel produced of fibrocement with cellulose (Bossenmayer, 2012).

Observing the net emissions of the panels, it is verified that the UFPR panel, due to its high content of wood, absorbs more carbon than it emits, with a favorable balance. All other panels emit more than they absorb.

IV. CONCLUSIONS

This study proved that the use of wood particles in some cementitious materials, like blocks and panels is very interesting for future constructions, with great potential to allow the construction industry to approach the goal of building "carbon neutral". The addition of wood particles to the cementitious products reduces their net GHG emissions. The work also demonstrates the potential of products with wood to neutralize part of the CO₂ emissions of the construction industry due to the property that the wood uptake carbon in its structure. It is also interesting to note that mixing wood particles in cementitious materials; it is possible to produce other products that can replace traditional materials collaborating a lot in the reduction of CO₂ emissions by the construction works.

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