AGROBLOC PROJECT: BIO-BASED CONCRETE MASONRY BLOCKS

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Abstract

Agricultural resources can be used after crushing to replace mineral aggregates in concrete. Being natural and renewable materials they convey a positive image and contribute to reducing the use of mineral aggregates that are extracted from quarries. In order to assess the application of these bio-based aggregates in the French concrete industry, a project was lead aiming at creating concrete blocks made of aggregates produced by the agriculture. This project was funded by Centre-Val de Loire region and lead by a local plant. Hemp, flax and miscanthus were chosen for this study as their cultures are widespread in the area. They are beneficial for agriculture soil and environment-friendly as they require few agricultural inputs.

Concrete made of bio-based aggregates is usually a very light material (200 to 500 kg/m^3) with low mechanical strength (less than 1 MPa compressive strength) and good thermal insulating properties. The study was focused on two main objectives. The first one was the formulation of bio-based concrete with more than 5 MPa in compressive strength. The second one was on trying to find the adequate consistency for the concrete in order to manufacture blocks on a vibrating press (ability to compaction and immediate mold release). Laboratory tests were conducted on cubic samples and on hollow blocks produced on a laboratory press.

Then tests were operated in a plant where masonry blocks and shuttering blocks made of hemp concrete were manufactured. These trials pointed out the necessity to adapt the settings of the vibrating press (cycle duration, frequency, amplitude). However they proved the capacity of producing the blocks in the plant with the usual tools. The field of application of the blocks needs to be defined because of the possible reduction of mechanical strength due to humidity and the high dimensional changes (drying shrinkage and swelling).

Keywords:

Hemp concrete, concrete masonry blocks, shuttering blocks

1 INTRODUCTION

Agricultural resources can be used after crushing to replace mineral aggregates in concrete. Being natural and renewable materials they convey a positive image and contribute to reducing the use of mineral aggregates that are extracted from quarries.

In order to assess the application of these bio-based aggregates in the French concrete industry, a project was led aiming at creating concrete blocks made of aggregates produced by the agriculture. This project was funded by Centre-Val de Loire region and led by a local plant, Rasori.

Hemp, flax and miscanthus were chosen for this study as their cultures are widespread in the area. They are beneficial for agriculture soil and environment-friendly as they require few agricultural inputs.

2 CONTEXT

The use of concrete made of bio-based aggregates is expanding. It is usually a very light material (200 to 500 kg/m^3) with low mechanical strength (less than 1 MPa in compressive strength) and good thermal insulating properties.

The behavior of bio-based concrete is very different from the behavior of traditional concrete. The high porosity of vegetal aggregates results in a very light concrete with high thermal and acoustic insulation properties. However, this concrete shows low mechanical properties, especially a low compressive strength, a low Young modulus and a high ability to deformation. In addition some chemical reactions may occur between vegetal particles and mineral binders. The setting of concrete can be strongly delayed. Bio-based concrete is also quite sensitive to humidity changes and it shows high swelling and shrinkage.

The use of this kind of aggregates for the production of concrete masonry blocks requires many changes in the composition of concrete. It is necessary for the concrete to reach a minimal compressive strength and to have the adequate consistency in order to be manufactured on a vibrating press (ability to compaction and immediate mold release).

First laboratory tests were conducted on cubic specimen with immediate mold release and on hollow blocks made on a laboratory press. Further tests were conducted in a plant in order to confirm the feasibility of the production of blocks with an existing industrial process. This article describes the results of the tests conducted in the plant.

These tests consisted in producing blocks with the concrete compositions previously defined in the laboratory. They provided concrete specimens with more a compressive strength higher than 5 MPa (measured on 10 cm cubic samples with immediate mold release).

The production of blocks on the laboratory press was not sufficiently representative of the conditions in the plant (especially regarding the disposals for the transportation of concrete and the duration between the mixing of fresh concrete and its arrival at the vibrating press).

The objectives of the project was to produce bio-based concrete masonry blocks with a compressive strength higher than 3 MPa and to manufacture these blocks on a traditional plant for concrete masonry blocks.

3 MATERIALS

3.1 Binders

As the objective of the project is to produce bio-based concrete with high mechanical strength, the type of cement in the composition is CEM I 52.5 R. A high amount of limestone addition is added to some of the compositions in order to maximize the compactness of concrete.

3.2 Mineral aggregates

Two types of siliceous sand are used in the compositions with granularity 0/1 mm and 0/2 mm. They improve the concrete compactness.

Two types of lightweight aggregates are also used: pumice and expanded slate. Their physical characteristics are presented in Table 1.

3.3 Bio-based aggregates

Three different natures of bio-based aggregates are studied in this project: hemp shives, flax shives and miscanthus.

Two kinds of hemp shives were supplied:

- Hemp shives A are produced on a traditional device
- Hemp shives B are produced on an industrial device.

Flax shives come from seed flax. They detain a high rate of fibers.

Miscanthus aggregates are very fine. They have been produced with a very meticulous method that would not be possible for a large scale production.

These four different types of aggregate were submitted to laboratory tests and added to concrete compositions. The best results were achieved with hemp shives B. They are produced on an industrial device and are widely available. For these reasons they were selected for the production trials in the plant.

Pictures of the bio-based aggregates are shown on Fig. 1.

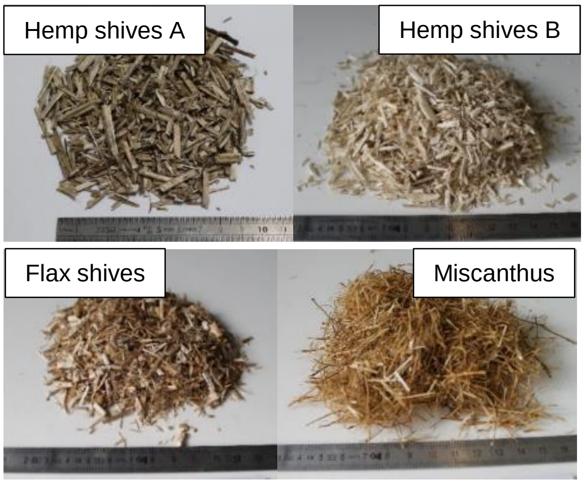

Fig.1: Pictures of the bio-based aggregates used during Agrobloc project

3.4 Admixtures

In order to counter the retarding effects of vegetal aggregates on the setting of cement, calcium chloride is used as a setting accelerator (36% dilution).

Superplasticizer and compacting agent are used to improve the consistency of fresh concrete and its ability to be used for the production on a vibrating press.

4 PRODUCTION OF BLOCKS IN THE PLANT

Five sets of production trials have been conducted in the plant so that the feasibility of using the concrete compositions, as defined in the laboratory, for the production of concrete blocks on an existing industrial device could be confirmed.

4.1 Method of production

Bio-based concrete blocks are produced as follows:

- Plastic bags of hemp shives are emptied in the concrete mixer and mixed with some water for about one minute;
- Cement, limestone addition (if used in the composition), sand and lightweight aggregates are added to hemp shives in the mixer and mixed for about one minute;
- Calcium chloride is added;
- Water is gradually added until the consistency of concrete seems adequate for the production (visual and manual verification).

Fresh concrete is carried to the vibrating press by a conveyor.

Tab. 1: Physical characteristics of lightweight aggregates

	Granularity	Density	Shape	Water absorption after 24 hours
Pumice	2 to 10 mm	1.1	Crushed	20%
Expanded slate	3.15 to 9 mm	1.3	Crushed	11.2%

After the production on the vibrating press, two fresh blocks are measured and weighted in order to estimate the fresh density of concrete. The other blocks are kept in heating chambers for 48 hours. Then, they are stored on pallets outdoors or in the laboratory.

4.2 Molds

Three types of molds were used for the production trials:

- Usual mold for perforated masonry blocks;
- Usual mold for shuttering blocks;
- Specific mold “Agrobloc” that was conceived specifically for the project. It is higher in order to maximize the compaction of concrete. Holes are used to facilitate the drying of concrete. The shape of the block is simple for economic reasons as this is a trial mold. The definitive shape of the block should be studied to improve the thermal resistance.

4.3 Concrete compositions

Five set of production trials were conducted in the plant:

- A first one that aimed at adjusting the process of production to bio-based concrete blocks. Perforated masonry blocks were produced with compositions A1 and A2;
- A second one for the production of perforated masonry blocks with new concrete compositions defined after the first trials in order to improve consistency and mechanical strength of concrete (compositions B1 to B7);
- A third set of trials with the specific Agrobloc mold (compositions C1 to C4);
- A fourth set, similar to the third set but with different storing conditions (compositions D1 to D4);
- A fifth set of trials for the production of shuttering blocks (compositions E1 to E4).

Compositions are given in Tab. 2.

4.4 Production of blocks

The first set of trials aimed at comprehending the behavior of hemp concrete on the industrial device and at defining the adequate consistency of concrete. Concrete compositions were modified after this first set of trials and no difficulty was met during the following trials.

Concrete compositions with hemp shives have the proper consistency for the production of blocks. Fresh blocks are stable and can be carried with usual plant devices.

During the first production trial with composition A1, concrete tended to agglomeration and the filling of molds was not satisfying. Because of water absorption by hemp shives, the consistency of concrete was modified after about 10 minutes and the filling of molds improved. The production of blocks became possible. After the production of 10 boards, the concrete hardened and obstructed the hopper. The production of blocks was temporarily interrupted.

For the following trials, superplasticizer was not used and water content was reduced. The ability of fresh concrete to fill molds was improved. The appearance of blocks was satisfying.

Some other troubles were met with compositions with increased cement content (B4 and B5). Fresh concrete was sticky, tended to agglomerate and did not fill molds properly. Blocks were produced but they did not show a high compactness.

4.5 Adjustment of the vibrating press parameters

During the production trials, the parameters of the vibrating press were adjusted to hemp concrete. The fresh behavior of this kind of concrete is very different from the one of traditional concrete. It is therefore necessary to adjust the production cycle as follows:

- Increase the duration of shaking before pre-vibration in order to make sure that molds are properly filled with concrete (bio-based concrete does not flow as well as traditional concrete);
- Increase the amplitude and frequency of pre-vibration and compaction;
- Delay the unloading at the end of the cycle in order to avoid the swelling of blocks during mold release (this step is not necessary for traditional concrete).

5 CHARACTERISATION OF BLOCKS

5.1 Tests methods

Compressive strength of masonry blocks

Compressive strength of masonry blocks is measured according to the test method described in NF EN 772-1. Three blocks were tested for each concrete composition.

Mechanical strength of shuttering blocks

Mechanical strength of shuttering blocks was evaluated according to the test methods of NF EN 15498 that describes requirements for wood-chip concrete shuttering blocks.

Two mechanical tests are required:

- Tensile strength of struts (Fig.2);
- Flexural strength of faces (Fig. 3).

For the tensile test, a strut is cut out from a block and tested with a specific device on a compressive press (Fig.3).

For the flexural test, a face is cut out from a block and tested with a three-point flexural device (Fig.4)

Fig. 2: Tensile test of a strut from a shuttering block

Fig. 3: Flexural test of a face from a shuttering block

Moisture movements (shrinkage and swelling)

Moisture movements of blocks were evaluated according to the test method described in NF EN 772-14.

Tab. 2: Compositions of concrete

Ref.	Component (mass % of dry components)										Molds
	Hemp shives B	Pumice aggregates	Expanded slate aggregates	Cement	0/1 mm sand	0/2 mm sand	Limestone addition	$CaCl_2$	Compacting agent	Total water	
A1	6.6	13.3		10.5	16.5		49.1	3.8	0.1	21.5	
A2	6.6	13.3		10.5	16.5		49.1	3.8	0.1	15.8	
B1	7.5	8.6		20.0	59.8			4.0	0.1	15.3	
B2	7.6	8.7		19.9		59.7		4.0	0.1	14.9	
B3	7.4	8.5		30.2		49.8		4.0	0.1	13.9	Perforated blocks
B4	7.3	8.4		40.1	40.1			4.1	0.1	16.5	
B5	5.7	19.5		17.8	53.3			3.6	0.1	11.3	
B6	3.9	30.1		15.7	47.0			3.2	0.1	10.8	
B7	8.2	18.0		17.6	52.6			3.5	0.1	15.6	
C1	7.6	8.7		20.4	60.9			2.4		12.6	
C2	5.9	18.8		18.3	55.1			1.9		10.6	
C3	7.5		9.9	20.0	60.3			2.4		11.7	
C4	5.7		20.8	17.8	53.8			1.8		8.5	Agro-blocs
D1	7.7	8.5		20.3	61.1			2.4		14.7	
D2	5.9	18.4		18.3	55.3			2.1		13.0	
D3	7.5		9.8	20.0	60.3			2.4		13.7	
D4	5.7		20.5	17.8	53.8			2.1		12.2	
E1	7.6	8.5		20.3	61.2			2.4		14.7	
E2	5.9	18.4	9.8	18.3	55.3			2.1		13.0	Shuttering blocks
E3	7.5		20.5	20.0	60.3			2.4		13.7	
E4	5.7			17.8	53.9			2.1		12.1	

The test is performed on six blocks. Two metallic pieces are fixed to each block and the space between them is measured. Then:

- Three blocks are stored in an oven at 33 °C. After 21 days in the oven the space between metallic pieces is measured again in order to obtain the shrinkage value ;
- Three blocks are stored in water at 20 °C. After 4 days in water the space between metallic pieces is measured again in order to obtain the swelling value.

The value of moisture movements is the addition of the value of shrinkage and of swelling.

5.2 Perforated masonry blocks

The results of mechanical tests on masonry blocks are given in Tab. 3.

The compressive strength of masonry blocks manufactured during the first set of production trials is about 1 MPa. This result is much lower than the objective for the project (3 MPa). For this reason concrete compositions were modified for the next set of trials: different nature of sand, increase in cement and lightweight mineral aggregates content (see concrete compositions in Tab. 2).

B1 and B2 compositions contain the same proportions of dry components. Their differences compared to A1 and A2 compositions are as follows: reduction of pumice aggregates content, increase of cement content, replacement of limestone addition by sand. 0/1 mm sand is used in B1; 0/2 mm sand is used in B2. Compositions B3 to B7 derive from these compositions. For compositions B3 and B4, cement content was increased and sand content was reduced. For compositions B5 and B6, pumice aggregates content was increased and hemp shives content was reduced. For composition B7, pumice aggregates content was increased and cement and sand contents were reduced.

Water content was adjusted to each concrete composition in order to get the proper consistency of fresh concrete for the production on the vibrating press (visual and manual verification).

28-day compressive strengths of the blocks produced during this 2nd set of trials are presented on Fig.4 as a function of concrete fresh density. This figure underlines the influence of concrete fresh density on its mechanical strength.

Compositions B3 and B4, holding a higher cement content, show rather low compressive strength due to rather low density. These results are consistent with what could be noticed during the production of blocks: hemp concrete with higher content of cement flows less easily into the molds, which induces less compact blocks.

Concrete compositions made of 0/2 mm sand have lower strengths.

Composition B7 shows a rather low density because of a low content in fine grains (sand and cement). For this reason the mechanical strength is low.

During this second set of production trials, some blocks with a compressive strength around 3 MPa were produced with compositions B1 and B5. These compositions were selected for the third and fourth sets of production trials that were conducted with specific "Agrobloc" molds. New concrete compositions were also tested by replacing pumice aggregates with expanded slate aggregates.

Compressive strength of blocks was measured on the 28th and on the 60th days. The blocks that were produced during the third set of trials were stored outside until testing. The blocks that were produced during the fourth set of trials were stored outside until the age of 28 days. Then, they were stored in the laboratory until the age of 60 days. Test results are presented in Fig. 5 and Fig.6.

28 days compressive strength of the blocks that were produced during the third set of trials are promising as they reach 4 MPa. However, the compressive strength decreases strongly between 28 and 60 days. This could be explained by storing conditions of blocks. During the first 28 days of storing, the weather was warmer and drier than during the period between 28 and 60 days. Humidity has a negative impact on mechanical strength of bio-based concrete.

The influence of storing conditions on mechanical strength of concrete is confirmed by the test results of the fourth set of trials. 60 days compressive strength is much higher than 28 days compressive strength. It can be assumed that the decrease of mechanical strength in wet conditions is a reversible phenomenon.

Tab. 3: Tests results on masonry blocks

Ref.	Fresh density (kg/m³)	Compressive strength (MPa) 28 d.	Compressive strength (MPa) 60 d.	Dimensional changes (mm/m)
A1	1520	1.1	-	-
A2	1400	1.2	-	-
B1	1470	2.7	-	-
B2	1250	1.5	-	-
B3	1140	2.0	-	-
B4	1070	1.0	-	-
B5	1440	2.8	-	-
B6	1500	2.1	-	-
B7	1200	1.8	-	-
C1	1340	3.7	2.1	2.76
C2	1310	4.4	2.0	1.14
C3	1260	2.9	2.6	-
C4	1330	4.4	1.8	1.52
D1	1340	2.3	3.9	-
D2	1350	2.3	3.9	-
D3	1300	1.9	3.6	-
D4	1410	3.0	4.4	-

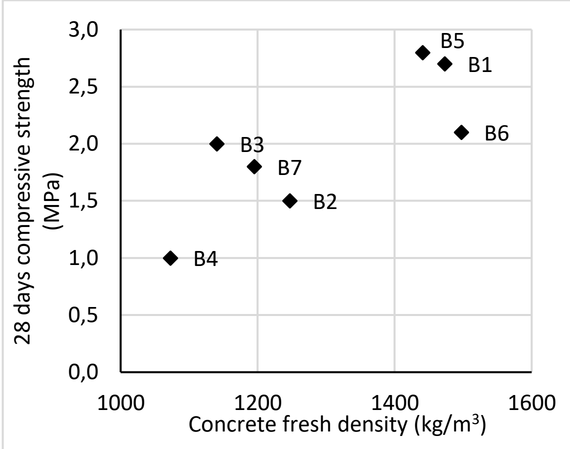

Fig. 4: 28 days compressive strength of blocks as a function of concrete fresh density (2nd set of trials)

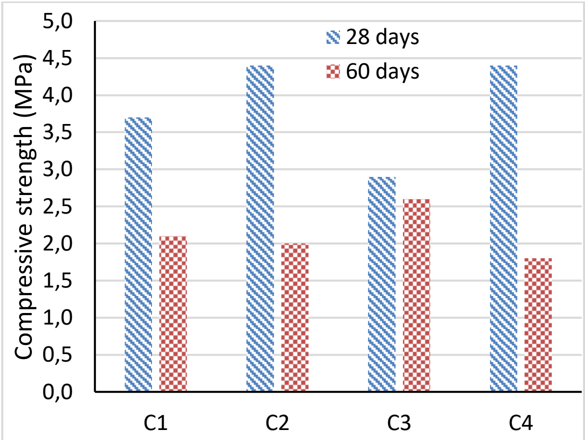

Fig. 5: Compressive strength of blocks produced during the 3rd set of trials

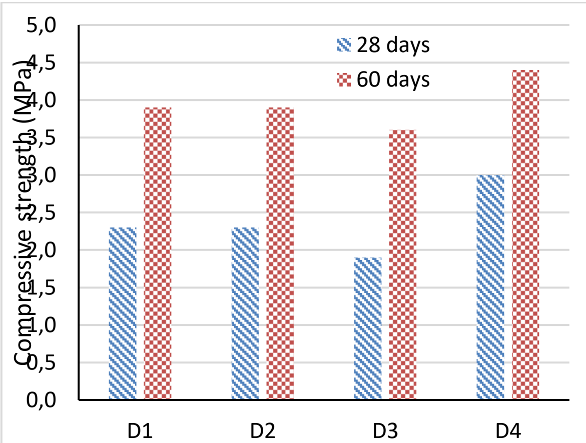

Fig. 6: Compressive strength of blocks produced during the 4th set of trials

5.3 Shuttering blocks

Minimal requirements for mechanical strength of shuttering blocks depend on the pressure applied on the blocks when fresh structural concrete is poured. Pressure values are given in Annex A of NF EN 15498 for concrete with a F4 consistency grade and a filling of two meters in 20 minutes. It also depends on the shape of the block. Minimal values for tensile strength of struts and flexural strength of face of the blocks produced during the 5th set of trials are given in Tab. 4.

Tab. 4: Minimal requirements for mechanical properties of shuttering blocks

Thickness of filler concrete	**Filling stress of concrete**	**Minimal requirement for tensile strength of struts**	**Minimal requirement for flexural strength of faces**
140 mm	0.0021 N/mm²	**0.22 N/mm²**	**0.45 N/mm²**
Thickness measured on the blocks produced during the trials	*Given by figure A.1 of annex A of the standard NF EN 15498*	*Calculated according to annex B of the standard NF EN 15498*	*Calculated according to annex C of the standard NF EN 15498*

Results of mechanical tests on shuttering blocks are given in Fig. 7 and Fig. 8.

All the compositions satisfy the requirement for flexural strength. Only one meets the requirement for tensile strength at the age of 28 days but all the composition satisfy this requirement at the age of 90 days.

Blocks were stored outdoors until the age of 28 days then in the laboratory. The results underlines once again the influence of storing conditions on the mechanical strength of concrete.

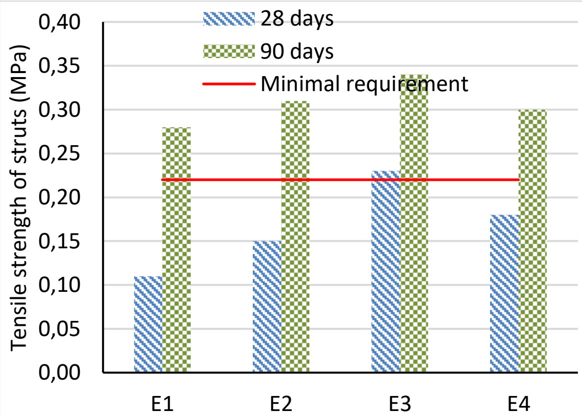

Fig. 7: Tensile strength of struts

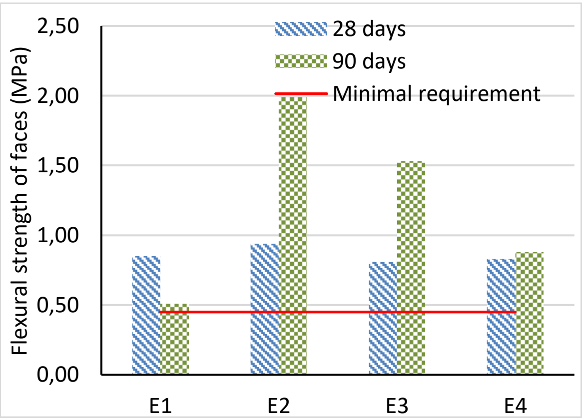

Fig. 8: Flexural strength of faces

5.4 Influence of the water saturation level of concrete on mechanical strength

French and European standards for mechanical tests on blocks require at least 14 days of storing in the laboratory before the test. For practical reasons this requirement was not fulfilled for all the tests during this project. The results underlines the essential role of storing conditions in the case of hemp concrete blocks.

Some blocks may reach the objective for mechanical strength when they are tested in accordance with standards but it is advisable to consider the behavior of the blocks in case of unexpected humidity (during the execution or the life of the building for example).

It is known that the saturation level of traditional concrete affects its mechanical strength. That's why specific storage condition are required by these standards. The phenomenon is much stronger in the case of bio-based concrete.

The increase of concrete strength when the saturation level decreases could be explained by the desaturation of pores that would increase capillary tensions (drying shrinkage). These tensions induce a prestressing of concrete and an increase in strength. [Zingg 2015]

Lightweight concrete is very sensitive to variations of saturation level because of its high porosity.

5.5 Moisture movements (shrinkage and swelling)

Tests results for swelling and shrinkage are given in Fig.10. They were performed on blocks from the 3rd set of production trials. Blocks were stored outside and tested at the age of 28 days.

The French standard NF EN 771-3/CN recommends a maximal value of 0.45 mm/m for dimensional changes of blocks. The results on Fig. 10 are much higher than this value.

The highest result is measured for composition C1. This composition contains more hemp shives than the other ones. Hemp shives are very sensitive to drying shrinkage and swelling in water.

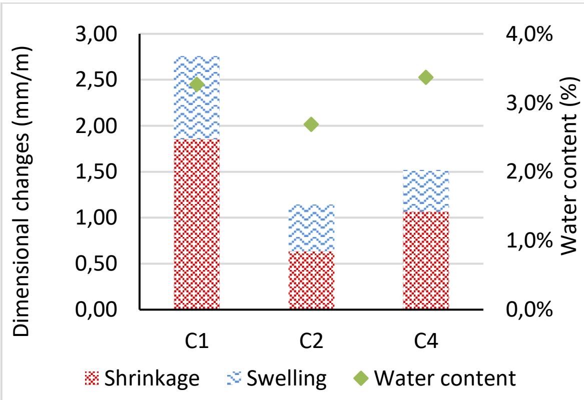

Fig. 9: Dimensional changes of blocks with compositions C1, C2 and C4

6 CONCLUSION

A method for the production of hemp concrete blocks was developed during the production tests in the plant. The production cycle for hemp concrete blocks on the vibrating press is stronger and longer than for traditional blocks.

Concrete compositions with hemp shives with the proper consistency for the production of blocks were defined during the project. Fresh blocks are stable and no difficulty was experienced during their transportation.

The compressive strength of hemp concrete masonry blocks is higher than 4 MPa. The mechanical performances of shuttering blocks meet the requirements of the standard NF EN 15498.

It appeared during the project that storing conditions strongly affect the mechanical performances of hemp concrete blocks. A storage in wet conditions can lead to a reduction of about 40% of the strength. Dimensional changes of blocks due to shrinkage and swelling might be higher than 2 mm/m. The field of use of these blocks should be defined and their durability should be studied. Filling tests of shuttering blocks would be necessary in order to validate their aptitude.

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