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# Carbonated concrete blocks for CO<sub>2</sub> captation

## *Karbonatyzacja elementów betonowych jako sposób wychwytywania CO<sub>2</sub>*

DOI: 10.15199/33.2015.10.35

**Abstract.** The CO<sub>2</sub> captation process called carbonation, improves specific properties of the concrete during the conversion of carbon dioxide CO<sub>2</sub> into calcium carbonate CaCO<sub>3</sub>. Current environmental concerns motivate the study of carbonation in order to maximize the absorption of carbon dioxide. Moreover, lightweight concrete with bio-based products knows an interesting development in the construction field, especially as thermal insulation panels for walls in buildings. Concrete blocks produced with miscanthus mineralized aggregates offer interesting mechanical properties and minimal environmental impact.

**Keywords:** carbonation, miscanthus aggregate, „green” concrete.

**Streszczenie.** Proces wiązania CO<sub>2</sub> z powietrza zwany karbonatyzacją, poprawia wybrane właściwości betonu na skutek konwersji CO<sub>2</sub> w CaCO<sub>3</sub>. Obecne analizy środowiskowe skłaniają do rozważania procesów karbonatyzacji jako sposobu zwiększenia absorpcji CO<sub>2</sub>. Ponadto wzrasta obecnie zainteresowanie stosowaniem betonu lekkiego z materiałami organicznymi pochodzenia roślinnego, szczególnie jako materiału termoizolacyjnego ścian zewnętrznych. Elementy betonowe z mineralizowanym kruszywem miskantowym wykazują korzystne właściwości mechaniczne i minimalny wpływ na środowisko.

**Słowa kluczowe:** karbonatyzacja, wypełniacz miskantowy, „zielony” beton.

Concrete products are sustainable building materials. Their compositions are based on natural, abundant and locally available raw materials. The concrete block manufacturing requires low cement content and almost no energy during the curing phase – there is no baking – which greatly limits CO<sub>2</sub> emissions.

At a time when the cement industry is largely responsible for the production of CO<sub>2</sub> in the construction sector, it is useful to make this production a reverse phenomenon: that's CO<sub>2</sub> capture. The CO<sub>2</sub> absorption process, called carbonation, improves specific properties of the concrete during the conversion of carbon dioxide CO<sub>2</sub> into calcium carbonate CaCO<sub>3</sub>. Current environmental concerns motivate the study of carbonation in order to maximize the absorption of carbon dioxide.

Finally, the use of bio-sourced aggregates such as miscanthus vegetal will decrease again the environmental impact of concrete blocks manufacture and increase insulating properties.

### Principles and advantages of carbonation

Carbonation is a chemical reaction between the cement paste and hardened carbon dioxide [1]. This reaction can

occur in a mature concrete between the hydrated products (CSH and Ca(OH)<sub>2</sub>) and CO<sub>2</sub>. The carbonation can also take place in the presence of moisture between the hydraulic components of clinker (C<sub>3</sub>S and C<sub>2</sub>S) and CO<sub>2</sub>. The proposal made here is to induce early carbonation by infusing CO<sub>2</sub> immediately after release. In the case of concrete building blocks, the carbonated products are improving concrete performances in terms of strength, durability and dimensional stability, thanks to the lower content or disappearance of Ca(OH)<sub>2</sub>.

During Seventies, mechanisms of carbonation were studied in relation with reactivity and strength of calcium silicate activated by CO<sub>2</sub> [13]. This technique was introduced for the production of panels cement fibre based, in order to reduce the manufacturing time; the first plant operating on this principle was built in Hungary in 1985, but was closed for reasons of cost of CO<sub>2</sub>.

A feasibility study of CO<sub>2</sub> sequestration through a technique of accelerated cure was conducted at McGill University (Montreal, Canada) between 2004 and 2006 [12]. The possibilities of fixing CO<sub>2</sub> in cement matrices were explored and performances in the short and long term implications were verified: it showed some interesting opportunities offered by this technique, based on specific accelerated carbonation process.

Currently, concrete blocks are produced on a wet cure (water vapor) based process. It is estimated that for 1 m<sup>3</sup> of concrete blocks manufacturing, wet cure at atmospheric pressure consumes 0,59 GJ while curing in autoclave consumes 0,71GJ [12]. If a CO<sub>2</sub> injection process is put in place, for the same volume of concrete, the energy for recovery and compression of CO<sub>2</sub> is estimated to be 0,02 – 0,10 GJ/m<sup>3</sup>, for a minimum value of CO<sub>2</sub> capture into cement of 10 and 50%, respectively. That means that the total energy, excluding CO<sub>2</sub> transport necessary to carbonation, is significantly lower than that required for a traditional wet cure.

The building blocks of concrete are particularly suited to carbonation, because of their mass production, their high porosity and the need to practice a wet cure. The reaction between the cement paste at early age and carbon dioxide thus constitutes a form of CO<sub>2</sub> sequestration. If we consider a hollow block 39 x 19 x 19 cm and 18 kg, which contains about 10% by mass of cement, we can consider that it is able to fix at least 0,18 kg of CO<sub>2</sub> [12]. If the cement is replaced by slag, the capture rate will remain about the same [8]. Furthermore, if the aggregates (86% by mass) are also used to fix CO<sub>2</sub>, the fixed amount considerably increases. Carbonated steel slag could set another 6% by

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mass. Therefore, if one considers that each aggregate is able to fix about 5% of its mass in CO<sub>2</sub>, a total sequestration of 0,77 kg may be attempted, for aggregates and a block. A block of concrete construction would be potentially able to fix 0,95 kg of CO<sub>2</sub>.

This concept could lead finally, if based on the adequate choice of materials for the „aggregate” part, to a situation of „zero-emission”. This will be the case if bio-sourced or recycled aggregates can be used [5]. Moreover, the accelerated carbonation blocks should lead to improved mechanical performances, lower porosity and a reduced risk of efflorescence: the denser microstructure of concrete, which improves the durability of the product and, therefore, the duration of life. Finally, the developed industrial process does not change the potential for recycling at end of life, particularly in the manufacture of new blocks.

**Materials**

**Miscanthus original aggregates.**

Compared to the hemp plant (annual) [7], miscanthus is a perennial plant, located for several years (up to 20 years), which reduces costs of crop establishment: energy consumption is evaluated around 9,223 GJ/ha (for hemp: 13,298 GJ/ha).

In comparison with wood, miscanthus has a high content of parenchyma, surrounded by a tough fibrous structure. It therefore combines a high rigidity with a low density [10].

Without woodchip pretreatments, the mixtures offer unstable results [11]. In addition, the stability of the concrete cannot be achieved because untreated chips react chemically with the environment and dimensions considerably vary with changes in humidity. In order to increase the durability of the composite and to reduce vapor or liquid transfers between the chips and their environment, the mineralization appears to be the best solution (Fig. 1). This treatment consists in soaking the chips with a mineral solution; a mixing procedure of about 3 min allows an impregnation of the chips. Currently, the components



Fig. 1. Miscanthus maepertus chips  
Rys. 1. Wypełniacz miskantowy

used for mineralization are mainly calcium chloride, silica fume and derivatives of lime and cement.

Physical characteristics of the chips, before and after mineralization, have been determined in order to point out the real effect of the mineralization process. A first important characteristic is apparent density: it gives a good idea of the capacity of water (liquid or vapour) penetration into vegetal aggregates but also thermal insulation properties. For porous materials able to adsorb humidity, it is important to define test conditions: density has been evaluated in dry conditions and in equilibrium with specific environment (21°C and 40% R. H.) (Table 1).

Table 1. Apparent density [kg/m<sup>3</sup>]  
Tabela 1. Gęstość objętościowa [kg/m<sup>3</sup>]

Sample	Dry conditions		21°C and 40% R.H conditions		
	Raw miscanthus	Crushed miscanthus	Raw miscanthus	Crushed miscanthus	Mineralized miscanthus
1	97	93	111	98	370
2	90	90	113	103	371
3	91	91	115	103	386
Average value	93	91	113	101	376

Water absorption also gives indication on the effect of mineralization. Most commonly tests used to analyze water transfer at the interface is the capillary suction test [2]. The capillary suction test is described by several standards: they differ essentially by the water level above the bottom surface of concrete specimen and the time when measurement is taken. Mass change is usually registered after 5, 15, 30 and 45 minutes, as well as after 2, 6 and 24 hours (Fig. 2). Mass is measured on samples wiped off with a damp tissue. From the capillary suction test, it is possible to calculate the coefficient of water absorption, which is related to the evolution of the mass of the specimen with time [2]. However, it was necessary to adapt the test to chips: samples of

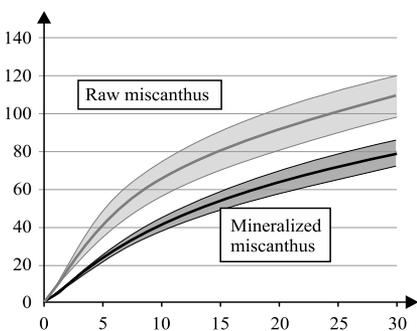


Fig. 2. Coefficient of absorption (%/dry initial mass) vs time (s) for raw materials  
Rys. 2. Zmiana względnego współczynnika absorpcji (%/masa w stanie suchym) w czasie (s)

particles, after being dried into an oven, are placed in nylon tights under water. The tights let the water go through without losing particles. The measurement of mass variation is not performed on one sample but on a pool, containing several chips to start. The measure may be slightly influenced by the size of the chips.

There is a clear difference in behavior between raw and mineralized miscanthus. New test procedure [3] allowed following what really happens in the first minutes of contact between chips and water, because it exactly corresponds to the time of mixing for mineralization process: finest particles offer an absorption rate largely greater than larger particles.

Mineralization induces a reduction of absorption rate [5]. However, there is a larger dispersion of the results, probably due to an incomplete process: more time should be needed to have a complete mineralization.

**Concrete blocks preparation.** Concrete blocks are produced with CEM I 52.5 N with the proportions given in Table 2.

Table 2. Mix proportions for miscanthus concrete blocks

Tabela 2. Proporcje składników próbek z betonu z wypełniaczem miskantowym

Components	Quantity (%)	Quantity (g/block)
Mineralized miscanthus aggregates	40.54	1335
Cement CEM I 52.5 N	24.32	803
Water	35.14	1150

Mixing and casting procedure for concrete blocks (Fig. 3) is inspired by the work realized by Delhez and is described in details in [4].

A CO<sub>2</sub> injection technique procedure was set up: an air-conditioned room called *incubator*, with controlled humidity and temperature and specific CO<sub>2</sub> injection system connected to the incubator have been used. The following three parameters can be taken into account by the latter: the temperature, the relative humidity and the

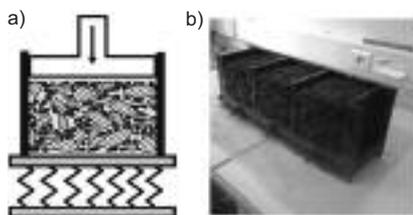


Fig. 3. Preparation of the samples: (a) vibration and loading principles, (b) demoulding of the concrete blocks

Rys. 3. Przygotowanie próbek: (a) schemat zagęszczania i obciążenia, (b) rozformowane próbki

percentage of injected  $\text{CO}_2$ . The temperature is controlled using a thermostatically controlled bath while relative humidity is achieved by means of a saline type  $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ . Incubators available in the lab allowed to work with rate of 20% and commercial  $\text{CO}_2$  [9].

## Results and discussions

**Carbonation of miscanthus aggregates.** After mineralization process which includes cement, silica fume,  $\text{CaCl}_2$  and superplasticizer, miscanthus aggregates are stored into incubator for 7 hours and mass increase is registered for 1, 3 and 7 hours, respectively. Aggregates are disposed in such a way that  $\text{CO}_2$  is able to diffuse from all the faces. Quantification of  $\text{CO}_2$  gain mass (Table 3) is based on Monkman equation [6].

Table 3. Quantification of  $\text{CO}_2$  absorption by miscanthus aggregates

Tabela 3. Szacowanie absorpcji  $\text{CO}_2$  przez wypełniacz miskantowy

Variables	Sam- ple 1	Sam- ple 2	Sam- ple 3	Total
Initial mass (g)	363.52	422.34	325.37	1111.23
Final mass (g)	363.20	421.95	325.06	1110.21
Water loss mass (g)	6.34	7.37	5.68	19.40
Dry binder mass (g)	118.80	138.02	106.33	363.15
Mass gain (%)	5.07	5.06	5.05	5.06

Miscanthus carbonated aggregates are more resistant to wear than those who were not carbonated [6]: carbonated chips have a Micro-Deval coefficient of about 7,23, while those who were not carbonated get a coefficient approaching 12,69. We can say that the  $\text{CO}_2$  capture on plant fibers miscanthus type is positive from mechanical point of view and should positively influence the compressive strength of blocks.

Concrete blocks were stored in two types of curing conditions during 7 hours:

- wet climatic room (100% R.H.);
- incubator with 20%  $\text{CO}_2$ .

Compressive strength of blocks (Table 4) is 5 times higher when stored in  $\text{CO}_2$  incubator, even if it is quite low. But the objective is to obtain insulation materials and not structural elements. The average compressive strength of these blocks is almost 7 times as large as the blocks stored in a humid chamber. It is also four times greater than that of concrete blocks made from non-carbonated mineralized miscanthus.

Table 4. Compressive strength of concrete blocks after 7 hours

Tabela 4. Wytrzymałość na ściskanie próbek po 7 godzinach

Test	Compressive strength (N/mm <sup>2</sup> )		CO <sub>2</sub> mass gain (%)
	Wet Curing	CO <sub>2</sub> Curing	
miscanthus aggregates			
1	0.0091	0.0522	1.49
2	0.0091	0.0689	1.14
3	0.0091	0.0546	1.36
Average	0.0091	0.0586	1.33
carbonated miscanthus aggregates			
1	0.0275	0.202	1.43
2	0.0285	0.209	1.23
3	0.0314	0.205	1.37
Average	0.0290	0.205	1.34

## Conclusions

On the basis of the experimental results, the following conclusions can be drawn:

■ capture of  $\text{CO}_2$  in concrete blocks proves to be a good alternative for the environment and, more specifically, in the fight against global warming through limiting greenhouse gas emissions;

■ use of bio sourced materials like miscanthus requires a mineralization process in order to guarantee a minimum rigidity and to reduce water absorption capacity;

■ carbonation of bio sourced aggregates before concrete blocks production can increase concrete blocks performances;

■ the strength of concrete blocks is increased by using  $\text{CO}_2$  injection, with regard to classic humid curing.

Optimization of  $\text{CO}_2$  injection process is however needed, taking into account carbon dioxide concentration and humidity, in order to increase strength performances of concrete blocks.

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