DURABILITY STUDY OF PVA FIBRES IN FIBRE-CEMENT PRODUCTS

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Abstract

In this study, results are presented concerning the long term behavior of PVA fibres in fibre-cement products used for roofing and cladding applications. In a first part, we analyse the temperature and environment conditions under which PVA fibres can degrade. It is shown that a decrease of the fibre tensile strength does occur when fibres are immersed for more than 6 months in warm (>40°C) cement saturated solutions, while no significant changes occur at lower temperatures in the same period of time. Further, in order to assess the likelihood of such a degradation in the fibre-cement matrix under outdoors weathering conditions, we investigate by modelling and experimentation the hygrothermal behaviour of fibre-cement slates exposed to mid European climate conditions. It is shown that high moisture contents are accompanied by temperatures lower than 20°C. Microscopy analysis further reveals that fibres are well bound to the cement matrix allowing little micron size porosity around them. Finally, we investigate the physico-chemical properties of aged fibre-cement products as well as those of the fibres which were extracted from them. From these data, it is shown that fibres do not substantially degrade upon exposition of the investigated fibre-cement products to natural weathering.

1. Introduction

New Technology ("NT") fibre-cement products have been produced for about 20 years by different European manufacturers for roofing and cladding of private, agricultural as well industrial buildings. The production technology is mainly the Hatscheck process, which is named after its Austrian inventor. As far as roofing materials are concerned, the reinforcing fibres have been mainly polyvinyl alcohol (PVA) fibres.
While the ageing behavior of these products under natural weathering conditions is found to be satisfactory, no complete and systematic study of the ageing mechanisms related to a possible degradation of these PVA fibres has been performed to date. Results from a preliminary durability study were published by S. Akers et al. (1989). The present research program was set-up by a

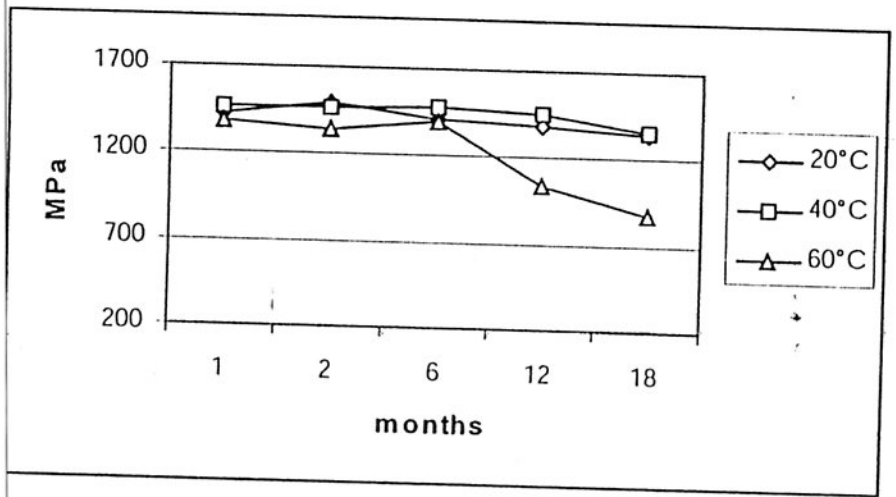
working group involving fibre-cement manufacturers, universities as well as a PVA fibre manufacturer in order to further investigate the long term behaviour of these building products, with emphasis on the durability of the fibre itself.

In the first part of this research, we analyse the temperature and environment conditions under which PVA fibres degrade.
Further, in order to assess the likelihood of such a degradation in the fibre-cement matrix under outdoors weathering conditions, we investigate by modelling and experimentation the hygrothermal behaviour of slates exposed to mid European climate conditions, as well as the microstructure of the fibre-cement interface.
Finally, fibres were extracted from aged fibre-cement products and their physico-chemical properties were evaluated.
Using the experimental and modelling results, we give evidence that fibres in slates exposed to weathering do not substantially degrade.

2. Degradation of fibres in alkaline solutions

The degradation of PVA fibres in a hot cement saturated solution was evaluated at Kuraray, Ltd (Japan) and at the Eidgenössische Technische Hochschule (ETH) (Switzerland) at 20, 40 and 60°C, according to experimental conditions which will be published elsewhere.

Although results do differ to some extent due to the somewhat different test conditions, both studies indicate a fibre degradation after 6 months exposure, when the temperature exceeds 60°C (Kuraray) or 40°C (ETH) (Fig. 1 & Table 1).



gure 1. Evolution of the tensile strength of PVA fibres immersed in cement saturated water in nction of the time (experiment by Kuraray, Ltd)

Table 1. Tensile strength of PVA fibres immersed in cement saturated water for 6 months (experiment by ETH).

	Tensile Strength (N/mm2)	Tensile strength (%)
Reference	1660	100
20°C	1694	102
40°C	1498	90
60°C	1397	84

3. Simulation of the hygrothermal behaviour of the fibre-cement slate:

The aim of the present section is to numerically simulate the moisture and temperature condition prevailing in the fibre-cement slates when exposed to middle European climatic conditions.

This requires first a determination of the basic physical properties of the slates, including open porosity, vacuum water saturation content, bulk density, moisture retention curve, pore size distribution as well as liquid and vapour water permeabilities (Carmeliet and Roels, 2001; Carme and Roels, 2002).

Three main pore sizes were identified by the mercury intrusion technique: a very fine size (10^{-9} to 10^{-8} m) associated with the cement gel phase, an intermediate pore size of 10^{-8} to 10^{-7} m and a coarse size (10^{-7} to 10^{-5} m) linked to various product inhomogeneities.
The simulation itself was based on the "Delphin4" calculation model of the Technical University Dresden (J. Grunewald, 1997) allowing to predict heat and mass transfers in function of natural climatic conditions. Climate conditions chosen here were those of North and South Germany.

From this modelling work, it appears that the slate experiences high mean moisture content durin the winter and many drying/wetting cycles during the summer. Wetting mechanisms are rain, hygroscopic adsorption and undercooling condensation. Drying is only possible by water vapour diffusion and is therefore slower than wetting. Very fine (hygroscopic) pores are filled by water about 80% of the time on a yearly basis, while larger (capillary) pores are either never filled (cent of the slate) or only filled 20% of the time in the top and bottom layers (1 mm) of the slates at temperatures < 20°C.

High moisture contents in the slates are accompanied with temperatures lower than 20°C (Fig. 2). For higher temperatures (>40°C), only hygroscopic pores with a radius < 10^{-9}m will be filled with water. The cumulated time during which the slates are exposed to temperatures during one year is limited, i.e., 15 days at >40°C and 3 days at >60°C.
In other words, when the temperature of the slate rises, it dries out, at least at the top and bottom layers, and even within the center of the slate, it remains well below the saturation point which is i this case 269 kg/m3. The combination of high moisture and high temperature which has been observed to be dangerous for the stability of the fibre has thus a low level of probability of occurrence along the year. Additionally, water is most of the time confined to the finest pores whe moisture transport is rather low (water vapour diffusion and adsorption instead of capillary transfe

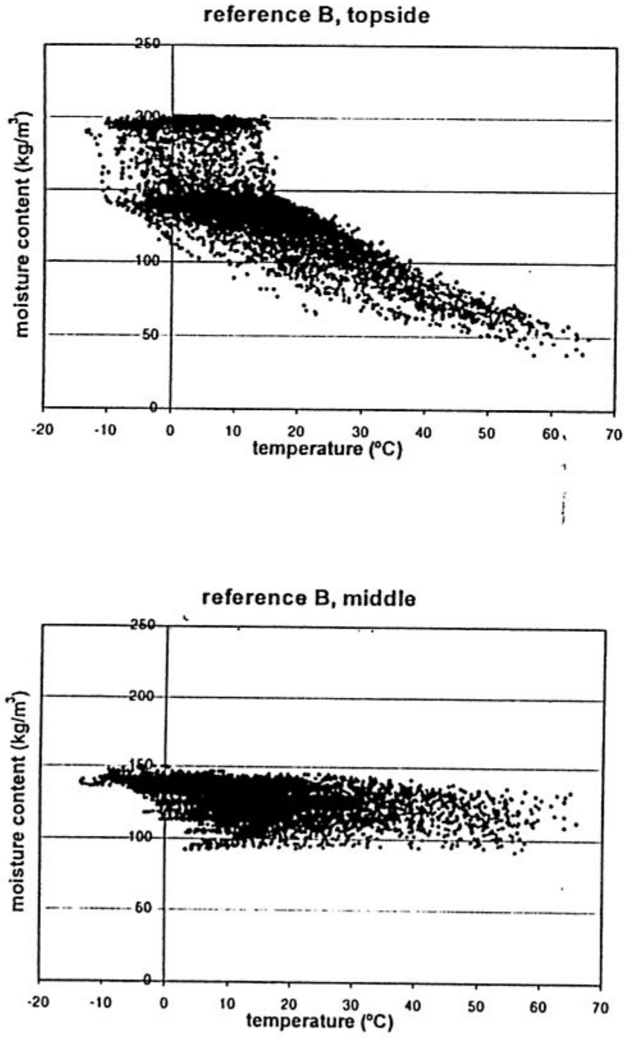


Figure 2. Simulated moisture content distribution over one year at the top side ("reference B, topside") and in the middle ("reference B, middle") of a slate as a function of the temperature at the respective positions, for weather conditions corresponding to middle Germany.

4. Microscopical investigation of the fibre-cement interface

From the preceding section, it appears that the pore size distribution shows three main subsystems. The question which is the object of the present section is to know whether significant amounts of large pores (micron size), where water and associated ions can move most easily, can be found in the vicinity of the fibres.

This was done applying an image analysis technique to SEM pictures of slate cross sections recorded in the backscattered mode. This allows to quantify the relative amounts of different ph: pores (> 1µm diameter), fibres, hydrated cement gel, unhydrated clinker particles (W. Saenen et 1995).

From the results shown in Fig. 3, it appears that the amount of micron size pores in unaged slate rather low (4 to 7 volume %) and further reduces with ageing (2 to 3 vol. %) due to carbonatatio and hydration reactions. Further, such large pores are either evenly distributed or even less prese in the vicinity of the PVA fibres than at other locations. This can presumably be explained by th high affinity of the fibre surface for the hydrated cement gel. The fibres are thus well encapsulat by the fine porous mineral phase and are therefore not exposed to high degrees of moisture saturation.

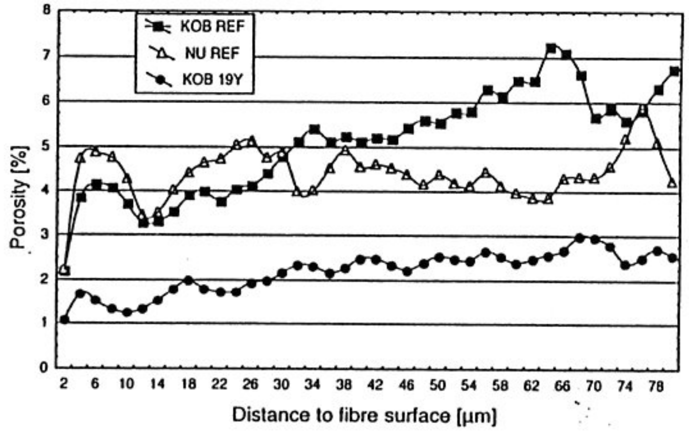


Figure 3. Percentage porosity in the vicinity of PVA fibres. KOB REF = unaged slate from Belg KOB 19Y = slate from Belgium after 19 years outdoors weathering, NU REF = unaged slate fro. Switzerland.

5. Natural and accelerated weathering: fibre and fibre-cement propert

In this last part, we analyse the properties of different fibre-cement products as well as of fibres extracted from them which have been exposed to natural as well as to accelerated ageing conditi Aim is to analyse whether fibre degradation has occurred.

5.1. Natural weathering

Corrugated sheets, slates and façade sheets were sampled from ageing sites in Switzerland and in Belgium after up to 18 years exposure and their bending strength was compared to the original values. Corrugated sheets are produced with or without post compression and their density ranges between 1.60 to 1.75 g/cm3 in the first case and 1.4 and 1.55 g/cm^3 in the second one. They are referred hereafter as high density and medium density sheets. As appears from fig. 4, the strength of the slates and of the façade sheets was found to be higher than before ageing, while for corrugated sheets, the strength was either unchanged (medium density sheets) or somewhat (- 5%) reduced (high density sheets). From physico-chemical analyses of the products, it appeared that they all had increased in density, while their degree of hydration as well as of carbonatation had similarly increased.

Product embrittlement (toughness reduction) with age was evident and can be related to the matrix changes and corresponding increase of the fibre-cement interfacial bond.

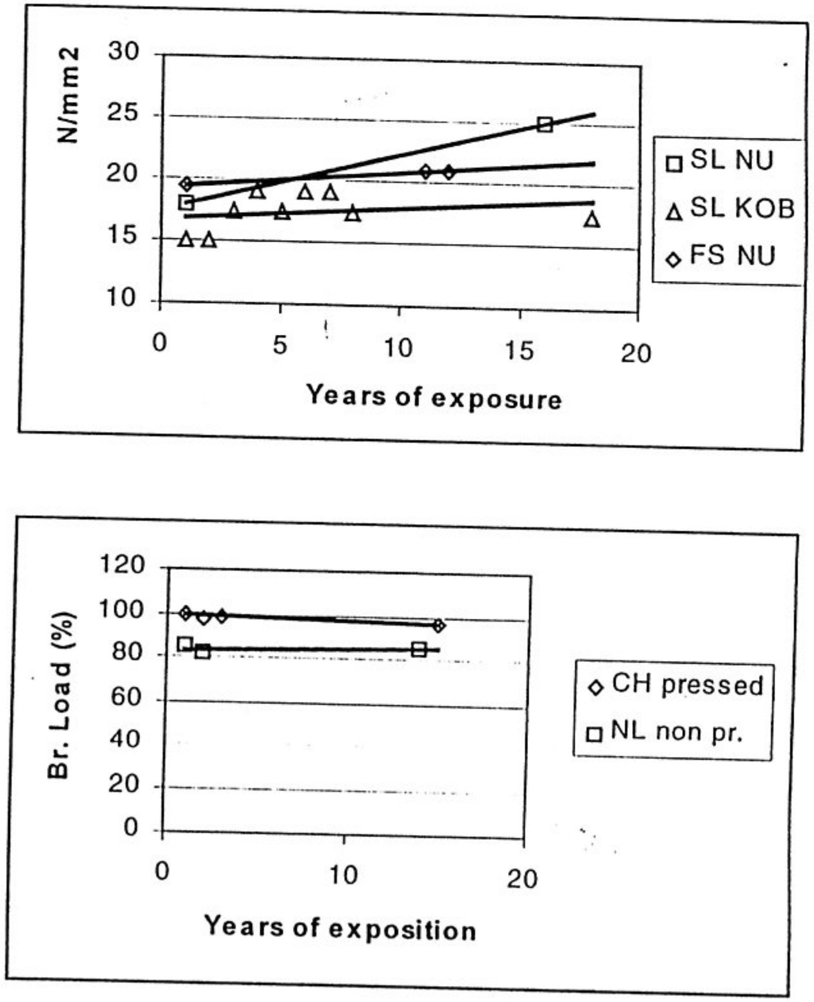
As appears from Table 2, the properties of the fibres which were extracted from the sheets did not indicate any significant change as compared to the original values.

Table 2. Tensile strength, crystallinity and molecular weight of PVA fibres extracted from naturally aged and from unaged products

FIBRE PROPERTIES	Tensile Strength N/mm2	Crystal-linity %	Mol. weight
14 yrs aged medium density corrugated sheet Belgium	1180	56	141.000
15 yrs aged high density corrugated sheets Switzerland	1240	54	133.000
18 yrs aged roofing slates Belgium	1100	58	153.000
16 yrs aged roofing slates Switzerland	1140	58	141.000
12 yrs aged façade panels Switzerland	1270	58	143.000
Unaged roofing slate Switzerland	1200	55	146.000

5.2. Accelerated ageing

The first accelerated ageing test consisted in a wet/dry cycling in a CO_2 rich environment, ("Beschleunigt Alterung CO_2", or "BAC" test) with the following sequence: 1) samples placed under water at room temperature (6 hr), 2) drying at 60°C (0.5 hr), 3) cooling with ambient air (0.5 hr), 4) CO_2 enriched air (25%) at room temperature (3hr), 5) drying at 60°C (3 hr), 6) cooling with ventilated ambient air (1 hr).



A)

B)

Figure 4. Fibre-cement strength evolution during natural weathering in Belgium and Switze
A) Roofing slates and façade sheets flexural strength; SL NU = slates/Switzerland; SL KOB slates/Belgium; FS NU = façade sheets/Switzerland.
B) Corrugated sheets breaking load; "CH pressed" = high density sheets/Switzerland; "NL n = medium density sheets produced in the Netherlands and exposed in Belgium. The breakin of the high density sheet before weathering is taken as the 100% reference.

A series of medium and high density sheets were made using a pilot machine which simulates the Hatscheck process for fibre-cement production. They were submitted to 1000 cycles of this test and the evolution of their properties as well as of those of the fibres extracted from them in function of the number of cycles is summarized in Table 3.

Table 3. Fibre-cement and PVA fibre properties during accelerated ageing test (BAC). Fl. Str.= Flexural strength, Poros.= total porosity; Hydr.= degree of hydration; Carb.= degree of carbonation, T. Str. = Tensile strength, Mol. Wt = Molecular weight.

# cycles	PRODUCT				FIBRE	
	Fl. Str. N/mm2	Poros. (%)	Hydr. (%)	Carb. (%)	T. Str. N/mm2	Mol. Wt
High density sheets						
0	22.0	12.0	47	8	1130	143.000
50	27.4	10.0	58	53	-	-
200	33.2	10.1	66	66	1290	138.000
500	29.0	9.8	74	73	1060	148.000
1000	30.4	-	-	-	-	-
Medium density sheets						
0	16.3	18.0	48	6	1180	157.000
50	19.3	17.8	45	51	-	-
200	20.7	12.2	66	91	1270	142.000
500	20.4	10.1	64	81	1130	166.000
1000	20.3	-	-	-	-	-

As can be seen from these data, the strength of the products first increases with the number of cycles and then stabilizes. Physico-chemical analysis of the aged products did reveal the same trends as observed in natural ageing, i.e., an increase in density, degree of hydration and carbonation. No significant changes were observed in the fibres properties, at least up to 500 cycles. The physico-chemical tests (degree of hydration, and carbonatation, porosity) on the samples submitted to the 1000 cycles and on the fibres extracted from them have not yet been carried out. However, we found already that the strength of the sheets for these 1000 cycles did not change in comparison with 500 cycles.

In a second test series, samples were submitted to the "warm water test" of the CEN 494 standard but prolonged up to 200 days instead of the prescribed 56 days. In this test, the products are left under water at 60°C until the end of the test.
Here again, the fibre properties after the test were not different from the properties of fibres extracted from the unexposed products (Table 4).

During this tes e degree of hydration and of carbonatation did not increase as much as in the BAC test and the porosity tended to increase rather than to decrease as in the BAC test or in the natural ageing. This results most likely from some form of leaching during the test.

Table 4. Fibre-cement and PVA fibre properties during exposure to the extended CEN warm wa test. Fl. Str.= Flexural strength, Poros. = total porosity, Hydr. = degree of hydration, Carb. = deg of carbonatation, T. Str. = Tensile Strength; Mol. Wt = molecular weight.

Time (days)	Product				Fibre	
	Fl. Str. N/mm2	Poros. %	Hydr. %	Carb. %	T. Str. N/mm2	Mol. Wt %
High density sheets						
0	22.0	12.0	47	8	1130	143.000
56	23.6	12.6	51	25	1110	146.000
112	23.3	12.8	54	21	1230	175.000
200	23.1	12.4	53	23	1160	158.000
Medium density sheets						
0	16.3	18.0	48	6	1180	157.000
56	16.4	18.1	45	32	1120	150.000
112	16.5	18.5	47	36	1240	158.000
200	15.4	18.7	46	38	1160	157.000

6. Conclusions

Although it appears that long term exposition of PVA fibres to hot alkaline solutions decreases their tensile strength, no signs of degradation could be observed on the fibres which were extrac from roofing and cladding fibre-cement products exposed to outdoors weathering for up to 18 y in Belgium and Switzerland.

It is hypothesized that the following factors do explain this:

- high temperatures in the exposed sheets are only accompanied with low moisture contents.
- The fibres are well embedded in the fine porous cement matrix with a small amount of micr size porosity.
- The cumulated yearly time during which the product temperature exceeds 40°C does not exc 15 days under the mid European conditions.

Such PVA fibre-cement products can thus be considered as durable.

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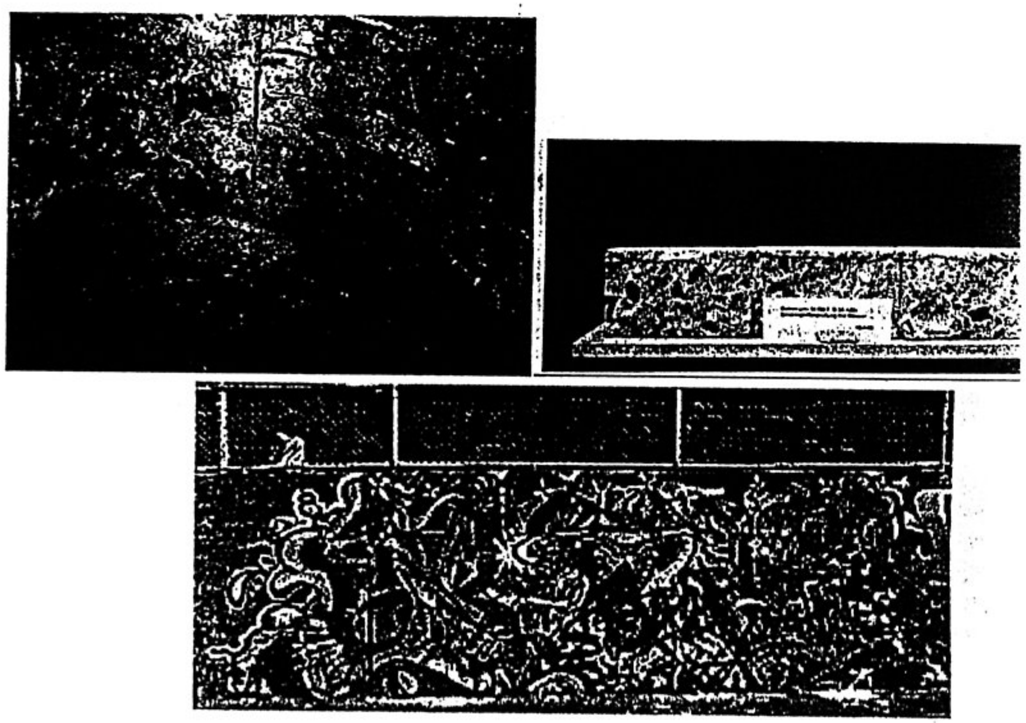
Concrete and environment



Concrete for a Sustainable Agriculture

Agro-, Aqua and Community Applications

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PREFACE

Society is evolving continuously. Priorities and emphases are changing fast. In agriculture as well as in the industry, there is an increasing demand for production methods to be sustainable, properly inspected and tightly controlled.

More specifically, the concerns of society are focused on:

- high quality food at a reasonable price, including guarantees for traceability in the entire food chain; people want to be informed about the place of origin of the agricultural products (e.g. meat, eggs, milk) they consume;
- a healthy environment to live in (which can be realised only by minimising the emission of pollutants to the soil, groundwater and air; and by slowing down resource depletion);
- animal welfare; consumers will not accept production methods in which animals are kept in barren environments or are suffering for other reasons.

These concerns of society have a strong influence on policy makers and result in new European, national and regional laws, rules and regulations. On the eve of the introduction of a new National Decree on the housing of laying hens and pigs, and the introduction of a new regional regulation on the reduction of ammonia emission from animal housing systems, this symposium could hardly have been organised at a more appropriate moment or place. The demand for alternative animal housing systems and sustainable bio-systems which meet requirements related to both animal welfare and environmental protection has never been more tangible. In this search for alternatives, the use of cement and concrete products has been questioned. Increasingly, other products such as wood, plastic, metal and organic materials (e.g. straw and sawdust) are proposed as substitutes…

This is the fourth symposium entitled "Concrete for a Sustainable Agriculture" following the ones at Noordwijkerhout (The Netherlands), Bologna (Italy) and Stavanger (Norway). This symposium offers the possibility to exchange knowledge and practical experiences about the application of cement and concrete in sustainable agro-, aqua- and community systems. We hope that these symposium proceedings are a useful scientific contribution to our field of research and perhaps also help enliven your memento of the paper presentations, the follow-up discussions, the meetings with scientists, farm building constructors, cement and concrete specialists, policy makers, … and of the city of Ghent.