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SUSTAINABILITY OF SELF-COMPACTING CONCRETE

Hubert WITKOWSKI *

[a] MSc Eng.; Department of Concrete Structures, Lodz University of Technology, Al. Politechniki 6, 90-924 Lodz, Poland
E-mail address: *eng.hubert.witkowski@gmail.pl*

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Abstract

Self-Compacting Concrete is referred to as one of the most advanced concrete technology nowadays, and a growing number of projects with its use, confirm this statement. A specific performance of SCC makes it one of the fastest developing concrete technology. However, in the face of growing demands associated with a sustainable development, technology of self – compacting concrete is no longer perceived as attractive, as a high content of cement, cause an increased value of carbon footprint. The question is whether the carbon footprint is the only measure of sustainability and the cement content is the only aspect determining a value of carbon footprint. A paper introduces some of issues related to environmental impact evaluation.

Streszczenie

Beton samozagęszczalny jest obecnie określany jako najbardziej zaawansowana technologia betonu, a rosnąca liczba projektów z jego zastosowaniem potwierdza powyższe stwierdzenie. Wyjątkowe właściwości betonu samozagęszczalnego sprawiają, iż jest to również jedna z najszybciej rozwijających się technologii. Jednakże w obliczu rosnących wymagań związanych ze spełnieniem wymagań zasad zrównoważonego rozwoju, technologia betonu samozagęszczalnego nie jest już postrzegana jako atrakcyjna z uwagi na dużą zawartość cementu, która powoduje większy ślad węglowy. Czy jednak ślad węglowy jest jedynym aspektem wpływającym na spełnienie zasad zrównoważonego rozwoju, zaś zawartość cementu jedynym czynnikiem determinującym ślad węglowy? W artykule zostały przedstawione wybrane zagadnienia związane z oceną wpływu tej technologii na środowisko.

Keywords: **Carbonation; Carbon Footprint; LCA; Self-Compacting Concrete.**

1. INTRODUCTION

In recent times, a requirement related to compliance with the principles of sustainability development has become an important factor in designing process. In this respect selection of technology and materials, next to safety, serviceability and durability aspects, has to meet environmental requirements. Different approaches in environmental design are assumed: a whole Life-Cycle Assessment (LCA) with all analyzed impacts, a Best Available Technology (BAT system) according to *fib Bulletin* 28 [1], or a limit of carbon footprint or other emissions. Choice of a method is related to various aspects depending on a project, but the purpose is always the same – to minimize an environmental impact in considered time period.

This assumption best meets LCA. Life Cycle Assessment is the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system during its lifetime. It usually consists of 4 stages: goal and scope, inventory analysis LCI, impact assessment LCIA and interpretation, as it has been presented in a Fig. 1. There are different scopes of approach to LCA regarding period of product's life, such as: cradle to grave, cradle to gate, gate to gate or gate to grave, as well as environmental performance. The primary ones are: energy consumption, solid waste, air pollution, global warming, resource use and others.

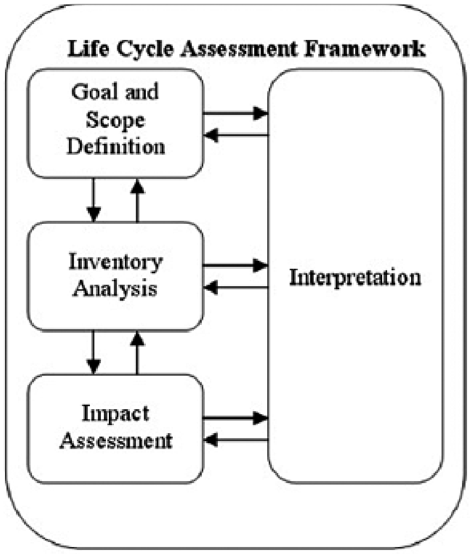

Figure 1.
Life Cycle Assessment Framework according to ISO 1440

Such an environmental approach is also reflected in concrete technology, and a number of "green concretes" has been elaborated in recent time. It is determined by a fact, that construction industry and built environment are responsible for about 40% of energy consumption and greenhouse gas emissions of the whole industry. And since a volume concrete is used in majority among construction materials, such a new approach to concrete structures and technologies is needed. The most common methods are reducing a cement content in concrete, or substituting aggregates or cement with a various type of by-products or various types of wastes. Although there is a number of researches on substituting concrete ingredients (e.g. [2, 3, 4]), there is a lack of information on quantitative environmental impact of research. Furthermore, the quantitative researches (e.g. [5]) often indicate reducing a cement content as a recipe for a "green" concrete. But does only the quantity of cement determines an environmental impact of concrete? In paper some considerations about a sustainability of Self – Compacting Concrete are presented.

2. SELF-COMPACTING CONCRETE

Self-Compacting Concrete is referred to as one of the most advanced concrete technologies nowadays and specific performance make it also one of the fastest developing. Recently presented examples of application of SCC on the 7th RILEM Conference on Self-Compacting Concrete by *Shink et. al*. [6] on execution of tall slender wall with white self-cleaning SCC and radiation-protection structures with heavyweight SCC, prove this statement. Developed in the late 1980s and managed by Okamura, SCC was a solution for a problem of low quality of structures resulting from lack of proper compaction of concrete in element. Due to specific composition, a high fluidity of Self-Compacting Concrete allows of complete filling formwork and achieving full compaction, even in presence of congested reinforcement.

However, in the face of growing demands associated with a sustainable development, technology of Self-Compacting Concrete is no longer perceived as attractive, as a higher content of cement, results in increased value of carbon footprint. Therefore a new type of SCC was developed where a cement content is reduced. According to *Wallevik* [7] in this aspect SCC are classified in Table 1.

Table 1.
Classification of SCC relative to its powder contend according to [7]

SCC type	Powder content (cement with binders)
Rich SCC	> 550 kg/m^3
Regular SCC	550 kg/m^3 – 450 kg/m^3
Lean SCC	450 kg/m^3 – 380 kg/m^3
Green SCC	380 kg/m^3 – 315 kg/m^3
ECO-SCC	< 315 kg/m^3

Although developing a new type of "eco" SCC became very actual, selected aspects of this issue are presented in the paper.

3. CARBON FOOTPRINT

One of the most often reflected aspect of environmental impact of concrete structures is carbon footprint. According to *ISO 14067* [8] it is a sum of greenhouse gases emissions and removals in a product system expressed as CO_2 equivalent. In this respect emission of CO_2, NO_x, SO_x,CH_4 and other gases are calculated according to table of Global Warming Potentials relative to CO_2 [8]. An example of such evaluation is presented in Table 2.

Table 2.
Global warming potentials (GWP) relative to CO_2 according to [8]

Industrial designation of emitted gas	Chemical formula	GWP for 100-year time horizon
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	NO_2	298
Sulphur hexafluoride	SF_6	22 800
Nitrogen trifluoride	NF_3	17 200

Table 3.
Comparison of GREEN-SCC and regular SCC referred by [9] with an example of industrial architectural SCC developed by Skanska

Concrete mix		GREEN SCC referred in [9]	regular SCC referred in [9]	regular SCC an example of Skanska recipe
Concrete class	-	C 30/37	C 30/37	C 30/37
Cement	kg/m^3	285	340	400
Fly – ash	kg/m^3	100	190	100
Sand 0/2	kg/m^3	700	652	744
Gravel 2/16	kg/m^3	1 060	985	873
Plasticizer	% C.m.	-	0.81	-
Super-plasticizer 1	% C.m.	2.24	-	-
Super-plasticizer 2	% C.m.	-	2.34	-
Super-plasticizer 3	% C.m.	-	-	1.00
Stabilizer	% C.m.	0.27	-	-
Water	kg/m^3	170	160	185
Density	kg/m^3	2 245	2 260	2 307

% C.m. – percentage cement mass

Table 4.
Comparison of GREEN-SCC and regular SCC CO_2 emission coefficient referred by [9] with an example of industrial architectural SCC developed by Skanska

Components of the concrete mix	GREEN SCC referred in [9]	regular SCC referred in [9]	regular SCC an example of Skanska recipe
PRODUCTION OF MATERIALS (kg eq. CO_2/m^3)			
Cement	265.06	316.21	135.2
Aggregate	3.27	3.04	3.00
Other components	0.05	0.05	0.05
Total	268.38	319.30	138.25
TRANSPORTATION OF MATERIALS (kg eq. CO_2/m^3)			
Cement	9.78	11.66	13.70
Aggregate	30.19	28.08	27.74
Other components	2.29	3.73	2.34
Total	42.25	43.47	43.78
PRODUCTION OF CONCRETE (kg eq. CO_2/m^3)			
Electricity	2.08	2.08	2.08
Diesel fuel	0.83	0.83	0.83
Fuel oil	0.98	0.98	0.98
Total	3.89	3.89	3.89
TOTAL EMISSION COEFFICIENT (kg eq. CO_2/m^3)			
Total	314.51	366.65	185.95

In case of concrete it is related to two aspects – emission of CO_2, especially production of cement process, which according to [1], is 749.5 kg/t and a total world's cement production, which is estimated to 14 200 000 tones. If compare those numbers, it is clear, how huge impact a concrete industry has on environment.

In this respect a new concrete technologies are developed and in number of publications a carbon footprints of various SCC type are compared to each other. Although in most respects the basis for comparison of GREEN-SCC or ECO-SCC with a regular SCC is its compression strength, it is clear that this type of comparison is erroneous. As for ECO- and GREEN-SCC application of pure portland cement and one type of powder is obvious, in the case of regular SCC which is a reference, application CEM I and only one type of powder is flawed. In practice concrete producers use a number of mineral additives or cements with a mineral components, such as a CEM III. It is determined not only by the environmental approach but primarily by economical aspects. In this respect, results of research can be surprising. Analysis of carbon footprint by *Wcisło and Kuniczuk* [5] of a GREEN-SCC and standard SCC prove a lower eCO_2 emission of GREEN-SCC, as both concretes had the same cement type and one additive type. If a compression strength of SCC is a reference parameter, a carbon footprint comparison of GREEN-SCC presented by *Wcisło and Kuniczuk* [9] with a regular SCC recipe e.g. developed by Skanska of architectural SCC on CEM III (with blast furnace slag) presented in Table 3 and Table 4, shows that a regular SCC can have a lower

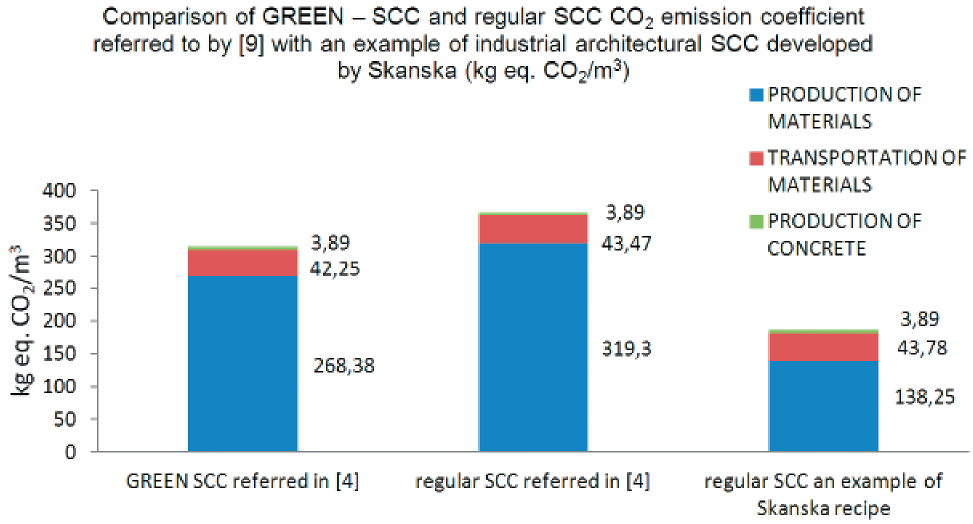

Figure 2.
Comparison of CO_2 emission coefficient presented in Table 4

environmental impact than specially developed GREEN-SCC, what is presented in Fig. 2.

Such result is an effect of two factors – application of blast furnace slag cement (CEM III) instead of Portland cement (CEM I) and lower aggregate quantity, as referred concrete developed by Skanska had higher cement content than GREEN SCC. Due to a content of granulated blast furnace slag (35-65%) that, not only reduces the amount of clinker, but also as a re-use of waste have zero emission, total emission of eCO_2 is significantly reduced. Amounts of eCO_2 emission of blast furnace slag cement were assumed according to [10].

In this respect other aspect emerges – a land and raw material use – with the lower cement content of GREEN – SCC and ECO – SCC, a higher quantities of aggregates are needed.

4. CARBONATION

Although very much attention is paid to number of emissions and other environmental impact in first stages (production of materials, transport, production of concrete, casting of concrete structure) of concrete structure LCA, reversed processes such as carbon uptake in maintenance and demolition stage are neglected. It applies not only to individual publications, but also to commercial programs for LCA evaluation.

Carbonation is the process when carbonate ions from dissolved carbon dioxide react with the Ca ions of cement paste and precipice carbonate.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

Generally process of carbonation is one of the concrete corrosion type, causing deterioration of its performance, but on the other hand, it reduces the impact of emission of CO_2 during production and casting stage. Process of carbonation depends on many factors such as: humidity, temperature, binder content, concrete quality, pressure of CO_2, and many others. According to [11] theoretically concrete during a whole life – time can uptake the same amount of CO_2 that has been emitted at production stage. But such assumption is very theoretical as this is very long – time perspective. Most of concrete structures are demolished before the period of 100 years, therefore specific calculations are needed. Process of concrete carbonation initially is rapid, but slows down with time, as a carbon dioxide must pass through alteration product. Therefore *Lagerblad* [11] has indicated, that most of the CO_2 uptake takes place in first 50 years. However, at the demolition and crushing of concrete, surface area exposed to process of carbonation rises, and process dramatically increase. According to different publications [11,12,13] total CO_2 uptake varies in different cases, but it can reach even 60% of total CO_2 emission, if demolition stage is assumed. Therefore further investigation of CO_2 uptake is needed, especially in relation to SCC.

5. ANOTHER ASPECTS OF TECHNOLOGY OF SELF-COMPACTING CONCRETE

Self-Compacting Concrete due to its properties is very often used in architectural concrete elements. Architectural concrete according to [14], is the concrete that will be permanently exposed to view and that requires special care to obtain the desired architectural appearance. It means that no other plaster work is applied on the surface. In most respects, most of plasters or other external layers are based on cement, what also has a negative impact on environment. According to computes from *BEES* programme developed by *NIST*, to produce and apply a 1 m^2 of cement plaster work, approximately 0.57 kg a of the equivalent of CO_2 is emitted.

Other aspect related to application of SCC as an architectural concrete element is a greater surface exposed to process of carbonation. In such respect CO_2 uptake is faster and greater.

As it has been stated above, one of the most significant aspects related to technology of Self – Compacting Concrete is lack of vibration to achieve full compaction of concrete. This property has also a measure value in aspect of environmental impact. According to [1] to compact concrete with flexible stick – type vibrator, 0.11 kg of CO_2/m^3 is emitted. Another aspect that is often not taken into account is lack of noise. Although noise is also an environmental impact, in a number of considerations it is simply ignored. This aspect is important, because a noise from flexible stick – type of vibrator can reach 75-80 dB, where a limit value of a noise level according to [15] for a residential development is 50- 65 dB.

6. SUMMARY

Aspects related to sustainable development became a mainstream problem, therefore an insightful analysis is needed. Presented aspects of environmental impact of SCC prove that:

- Cement content is not the only measure of carbon footprint, as an example of SCC with a furnace slag cement (CEM III) presented in paper indicated lower carbon footprint than GREEN-SCC with low cement content. Not only a quantitative analysis of cement content determines an environmental impact of SCC, but above all – qualitative.
- Although there are a number of programs and publications where emissions of eCO_2 are calculated at production of concrete and concrete structure, analysis of the whole life period (including demolition stage) and analysis of all processes is needed for a proper assessment of environmental impact. Therefore a process of CO_2 uptake has to be considered, as it has a significant impact on a total CO_2 emissions.
- Other aspects (e.g. presented in paper) determining environmental impact should be taken into account in evaluation.

Presented aspects related to compliance with the principles of sustainability development by SCC, lead to conclusion that it is necessary to carry out more specific research on carbon uptake in whole life cycle and also investigate possibility of application crushed concrete as a second aggregate.

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