ECOLOGICAL PERFORMANCE OF SELF COMPACTING CONCRETE

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ABSTRACT: Self compacting concrete (SCC) is increasingly used due to its advantageous technical properties. In general SCC has due to the special composition (e.g. higher binder content) the potential for a better durability compared to standard concrete. From an environmental point of view the reduction in noise emission and of the white finger syndrome, both related to the non necessity of compacting, are positively. In this paper the environmental properties are presented on the basis of the international recognised impact categories. Different SCC are compared to standard concrete on the basis of several normalised concrete properties like strength and permeability as well as different concrete compositions.
KEYWORDS: self-compacting concrete, ecological assessment, impact categories

1 INTRODUCTION

This paper is based on the document SIA D 0146 "environmental aspects of concrete" [9], published by the Swiss Society of Engineers and Architects in 1998 in German to 2001 and in 2001 in French and English.

For a long time, discussions within the building industry centred on technical aspects. Questions of environmental compatibility where also addressed in cases where an acute environmental risk was involved. This allowed a direct and serious risk to the environment to be avoided. Questions going beyond the acute environmental risk have been addressed more intensively in recent years. These arose from physics- and materials-technology-based approaches which also touched on ecological aspects, e.g. energy aspects. Since the 1980s, and more so in the 1990s, the general environmental compatibility of building materials is also increasingly being questioned and the optimal use of resources examined.

Which building material, in what composition and used in what applications, is the most advantageous in ecological terms? This frequently-raised question is difficult to answer. General environmental compatibility involves the effects on the environment during the production, use and disposal of concrete. What effects does the use of concrete have on the environment? This cannot be conclusively assessed.

Figure 1 shows how ecologically relevant the different tasks in the life cycle of a building project are, how wide the general discretion in making decisions is, and how costs develop. **Figure 1** indicates the importance of considering ecological aspects at the right time. Ecologically-relevant decisions are made at an early stage, i.e. before and during the project planning phase (e.g. new building or conversion, steel or reinforced concrete construction). In contrast, most costs only arise while work is being carried out and on completion. However, only very little influence can be exerted while this work is in progress in order to optimise the building ecologically by making changes in the project.

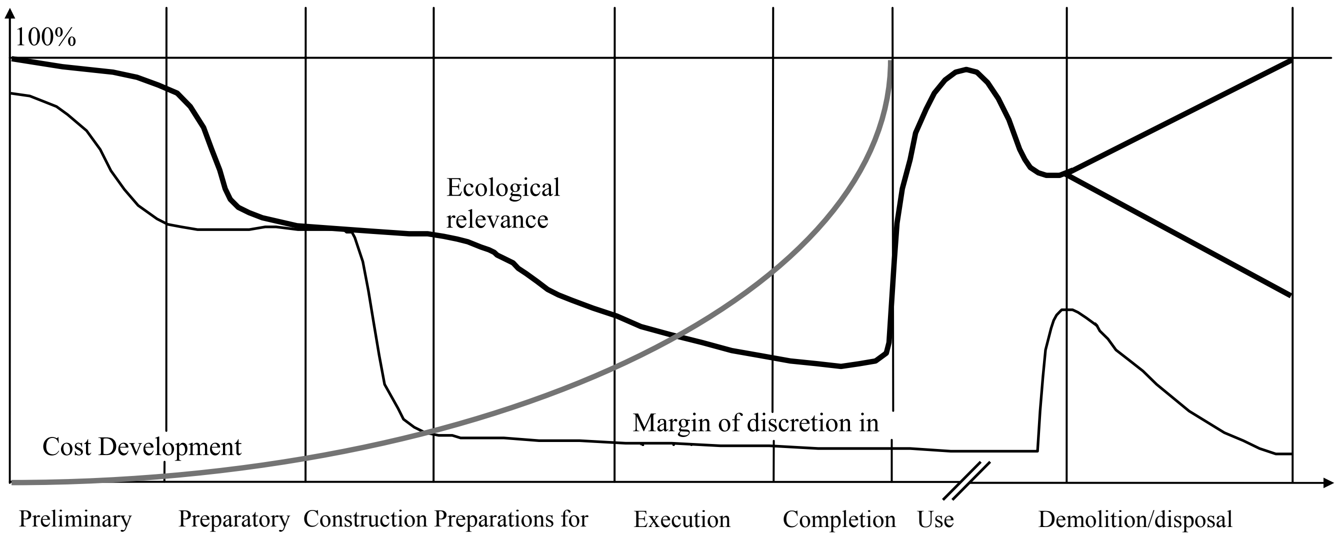

Figure 1: Possibilities of influencing a building project; see text for explanations

The planners are therefore obliged to include ecological questions at an early stage. The branching of the line at demolition/disposal illustrates the influences of the project planning on demolition and disposal. The ecological effects and the costs of disposal are influenced decisively by the choice of material and the structural design. If a material can be recycled – e.g. concrete, where this is as pure as possible – this is more advantageous than if it has to be disposed of at great expense.

2 APPROACHES TO DETERMINING AND ASSESSING ENVIRONMENTAL COMPATIBILITY

In order to build in the most environmentally-compatible way possible, criteria need to be determined and defined on the basis of which the most ecologically compatible building materials or building component systems can be selected. In terms of criteria, two developments basically stand out from the present viewpoint:

- assessment of selected aspects of environmental compatibility
- more general assessment of environmental compatibility

In assessing selected aspects of environmental compatibility, selective effects are considered. This can mean, for example, that

- the energy used in producing a building component, including the building materials used for this

- the leaching behaviour of heavy metals[1] from drainpipes
- the radioactive emissions from building materials and
- biological aspects

are considered. Various methods of ecological assessment are presented and discussed in [10]. For a more general assessment of environmental compatibility, all relevant ecological[2] and technical aspects, including the expected service life, are examined (see also [8]). This must be applied to components/structures with the same technical function. Examples of these include drainage pipes, wall constructions, ceilings and buildings. The results of these studies cannot readily be generalised, because components and structures can be location-specific. However, they furnish important initial indications regarding environmental compatibility. Different constructions may be necessary or possible depending on the nature of the ground, the intended use or the space available.

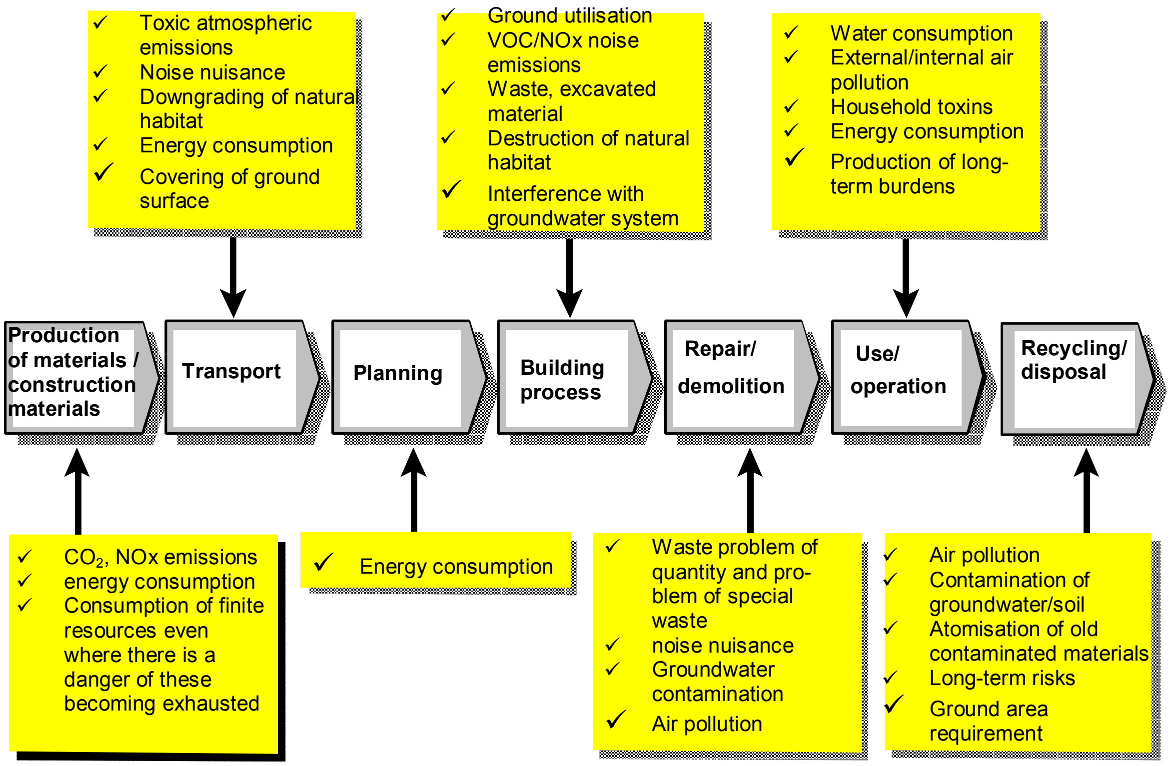

Figure 2: Effects of constructions on the environment, from their manufacture to demolition

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[1] Heavy metals are metals with a density greater than 3.5 to 5 kg/dm^3 (depending on definition). Heavy metals can be vitally essential (e.g. Cr, Co, Fe, Mn, Ni, Se, V, Zn, Sn) or toxic (e.g. Cd, Hg, Pb) to plants and/or animals, or both, depending on their concentration (e.g. Cu, Mo, Se).

[2] ecological building can mean an environmentally- and energy-conscious choice of location, building concept, form and position, choice of buildings, zoning plan and internal functional organisation, internal systems and the inclusion of vegetation with the aim of

- minimising energy and resource requirements in the construction and use of the building,
- intelligent use of natural systems and regenerable resources
- minimising the amount and concentration of air and water pollution, lost heat, waste, waste water and covered ground surface
- maintaining or increasing the variety of animal and plant life in the area
- low-impact integration of the building into the landscape and thus, ultimately, also making healthy living and working possible

These general ecological assessments are carried out "from the cradle to the grave". This means that, for concrete and its raw materials, the following aspects, among others, are of importance:

- production of raw materials for concrete
- production of concrete
- use and maintenance of concrete building components
- recycling of concrete

Selected effects on the environment of buildings, "from the cradle to the grave", are shown in **figure 2**. The environmental burdens differ greatly and occur over a long period.

Very widely-varying effects on the environment arise which cannot be compared directly with one another. For this reason, these have been classified into groups, so-called impact categories (see below). Further methods of assessing the various impacts are described in [8, 11]. At present, it seems sometimes practical to use two of these methods for a comprehensive ecological evaluation, in order to examine the results of the assessments on the basis of these methods.

These impact categories include, for example, human and eco-toxicity, i.e. all waste water and waste gases are examined to determine the extent to which they affect the health of humans (human toxicity) or animals and plants (eco-toxicity). Different impact categories are listed in **table 1**. Within an impact category, the impacts of different substances are added up (aggregated). In terms of greenhouse-impact potential, these include, for example, carbon dioxide, methane, nitrous oxide and CFCs , which are aggregated as carbon dioxide equivalents. Besides the impact categories, other additional criteria can be used for ecological assessment (**table 1**). Basic data for calculating the environmental impacts in the impact categories are provided in [1, 12]. In [8] for different building designs the environmental impacts in two impact categories are given.

If differently manufactured components/structures are to be compared, then on the one hand this must be done by impact category. On the other hand, it should be considered whether individual impact categories are relevant at the chosen site for the building measure. For example, there might be a requirement to keep eco-toxicity as low as possible because building will take place in a groundwater protection zone. A comparison between impact categories is difficult. If this is nonetheless done, it should be stated whether and why which impact categories are regarded as being more important than others. This must be done in as detailed a form as possible so that this evaluation can be checked and followed by third parties.

The assessment of impact categories has been developed considerably over the past decade. It still does not represent an all-embracing ecological assessment, but is restricted to that which is possible or necessary according to current knowledge. New scientific findings will lead to a further development of these methods.

Ecological assessments can also be used to evaluate different recycling/disposal channels (tipping, use in concrete etc.) for substances which occur as (by-) products of processes (e.g. for fly ashes from coal-fired power stations, excavated tunnel material, building rubble etc.). In addition, resource-management considerations should be applied. Possible means of increasing efficiency should be examined, both in the use of primary resources and also in the choice and processing of secondary resources. Resources should be assessed, processed and used in such a way that the individual component materials are used where they display their greatest benefit. A comprehensive product design is required which should, in particular, be aimed at where industrial by-products are used.

Table 1: Impact categories and additional criteria for determining environmental impacts, according to [2, 3, 6, 11]

Impact category	**determines**
Greenhouse potential	emissions in air which affect the heat balance of the atmosphere
Acid rain potential	emissions in air which cause acidification of rainwater
Oxidant generation potential	emissions in air which function as ozone generators near ground level
Ozone depletion potential	emissions in air which deplete the stratospheric ozone layer
Eutrophic potential	overfertilisation of soil and bodies of water
Eco-toxic damage potential	emissions in soil, air or water which interfere with plant and animal habitats
Energy requirement [a]	energy consumption, in some cases broken down into primary and secondary energy consumption
Usage of natural landscape[a]	duration and nature of change in natural landscape by man
Polluted or critical air-/water-volumes[b]	based on emissions, the national limit levels are used to calculate the volumes of air or water which would display the maximum permitted level of pollution
Waste generation[b]	quantity of waste generated, in some cases broken down into waste categories: special waste, waste for incineration, methods of dumping

[a,b] these are not impact categories, but additional criteria, in some cases governed by national regulations [b]

3 GENERAL ASSESSMENT

3.1 Preliminary remarks

Various sources of information are available on the measurement and/or evaluation of specific ecological aspects. The materials data safety sheets (i.e. complying with EU guidelines) address or provide information, according to standardised requirements, on specific ecological aspects. However much more general assessments will have to be made to consider the “real” ecological performance, only a few of which exist to date. These include not only aspects relating to production, but also to operation, maintenance and repair. There is a clear need for further general building-component-related studies on frequently-used components and constructions. Studies are published on the ecological evaluation of electricity pylons and of railway sleepers [4, 5].

3.2 Ecological Performance Of SCC

From an environmental point of view the reduction in noise emission and of the white finger syndrome, both related to the non necessity of compacting, are positively. The manufacture of SCC requires in general higher binder and admixture contents compared to standard concrete. Subsequently a comparison will be made between different SCC compositions and one composition of standard concrete. This comparison is based on the impact categories. It comprises all stages from the manufacture of the materials (e.g. coal mining) until the delivery of the concrete to the construction site. The filling of the mould, the compaction of the concrete as well e.g. as the recycling of the concrete are not considered, because no precise data are available and it is believed that these stages have a minor ecological importance compared to the considered stages as well as in those stages the differences between both types of concrete are small. The comparison is made on basis of the properties of the concrete and not e.g. per volume or mass. The properties of SCC differ partly greatly from standard concrete. Thereof a better durability (e.g. longer service life) or adapted element geometry (e.g. thinner walls) could result. The data for the ecological comparison results from German [7] and own investigations. The concrete compositions and properties (**table 2**) originate from different constructions in Switzerland.

Table 2: Composition and properties of considered SCC

Concrete mixes		standard	SCC 1	SCC 2	SCC 3
composition					
Cement CEM II/A-L	[kg/m^3]		450	430	
Cement CEM I	[kg/m^3]	300			350
blast furnace slag GGBFS	[kg/m^3]				110
fly ash	[kg/m^3]	0			
silica dust MS	[kg/m^3]	0		20	
superplatizicer	[kg/m^3]	0	7.2	7.2	14.7
w/(CEM+MS+GGBFS)	[-]	0.62	0.47	0.41	0.37
28 days properties					
compressive strength	[N/mm^2]	40.1	61	59.3	56.9
chlorid diffusion coefficient	[10^{-12} m^2/s]	19.7	16.3	8.9	7.5
capillary suction	[g/m^2 h]	6.6	4.9	4.7	6
gas permeability	[10^{-16} m^2]	0.49	0.44		

In **figure 3** the properties of SCC are related to the one of the standard concrete. The higher the values, the better the concrete performance like higher strength, lower diffusion coefficient, lower gas permeability, lower capillary suction. The values for SCC vary between 1.1 and 2.6. Due to the lower ratio of water to cementitious materials for SCC, the strength is much higher. The benefit of using silica dust or ground granulated blast furnace slag (GGBFS) on the chloride diffusion is obvious. Especially for the SCC containing GGBFS a still better performance can be expected at higher ages compared to the other SCC and standard concrete mixes, because the hydration is slower.

In **table 3** the environmental properties of the regarded concrete are presented. The environmental properties are calculated from the mix design (**fig. 2**) and the data in [7] as well as own data.

Table 3: Environmental properties (impact categories) and energy requirement of standard concrete and different SCC

	unit	standard	SCC 1	SCC 2	SCC 3
greenhouse potential	[kg/m^3]	268	350	335	317
ozone depletion potential	[kg/m^3]	6. 3 10^{-05}	7.9 10^{-05}	7.6 10^{-05}	7.4 10^{-05}
acid rain potential	[kg/m^3]	0.58	0.84	0.81	0.84
eutrophic potential	[kg/m^3]	0.068	0.11	0.11	0.11
oxidant generation potential	[kg/m^3]	0.061	0.085	0.082	0.080
renewable energy requirement	[MJ/m^3]	377	513	491	456
non renewable energy requirment	[MJ/m^3]	1041	1589	1526	1524

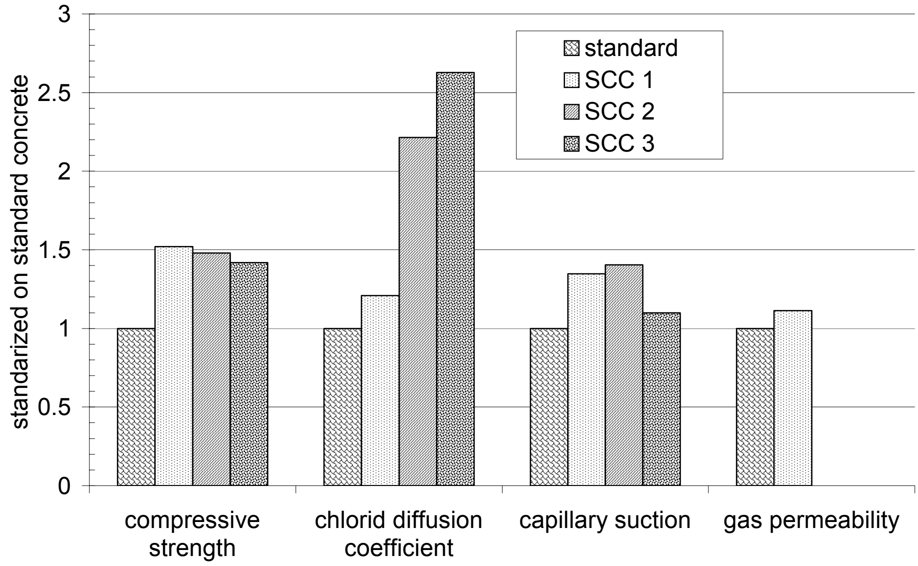

Figure 3: SCC properties related to standard concrete; a higher value means a better performance (higher strength, lower permeability...)

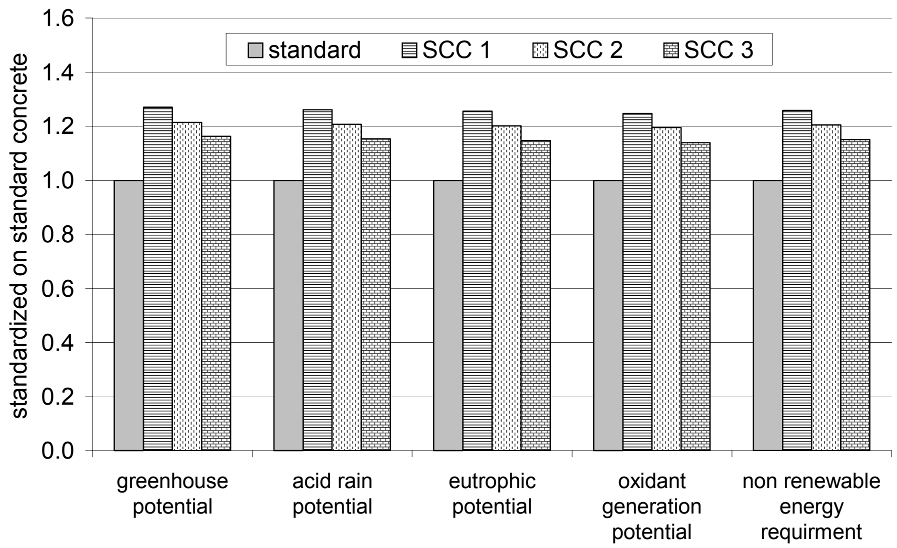

Figure 4: SCC impact categories and energy requirement related to standard concrete

In **figure 4** the values of the impact categories are related to the ones for standard concrete. The higher the value, the greater the damaging potential. It can be seen, that the values of the impact categories of SCC vary between a factor of 1.1 to 1.3 of the impact categories of the standard concrete. By comparing the results from **figures 3** and **4** an assessment of the ecological performance can be made. Regarding the compressive strength of the SCC, which are approx. 1.5 times higher than the standard concrete, it can be stated, that these SCC have a better eco-profile (lower values of the impact categories). If the eco-profile of SCC 3 is compared with standard concrete, a different picture is visible. If the comparison is made on the basis of the chloride diffusion coefficient than a better eco-profile results. If the capillary suction is compared, SCC 3 has a more worse eco-profile than standard concrete.

4 CONCLUSIONS

- ✓ The impact categories give a first, scientific based, assessment of the ecological impact. The method and the data have to be controlled and if necessary improved.
- ✓ The environmental impact of concrete is multiple. It is hardly possible to use one type of environmental impact like greenhouse potential or energy requirement as representative for all impacts.
- ✓ The composition of standard concrete as well as SCC has an great influence on the environmental impact.
- ✓ SCC is, on the basis of the impact categories, in general an environmental sound concrete, if the better performance is taken into consideration.

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