THE IMPACT OF CONCRETE ADMIXTURES ON THE ENVIRONMENT

Urs MAEDER maeder.urs@ch.sika.com
Sika AG, Tueffenwies 16, CH-8048 Zurich
René GAELLI, rene.gaelli@bmgeng.ch
BMG Engineering AG, Ifangstr. 11, CH-8952 Schlieren
Michael OCHS michael.ochs@bmgeng.ch
BMG Engineering AG, Ifangstr. 11, CH-8952 Schlieren

Abstract

Today quality concrete and mortars contain in most cases one or more admixtures. Concrete and mortar admixtures are designed substances with the aim of influencing their fresh and hardened properties by their physical or chemical action. For example, in the case of fresh concrete the flow, the cohesiveness and the setting behaviour are controlled but also the hardened concrete properties such as strength, impermeability, shrinkage, or freeze thaw resistance can be positively influenced by the use of a concrete admixture.

Because of their low dosage concrete admixtures play a subordinate part in the multi-component system concrete. Nevertheless it is the task of a construction chemical producer to evaluate the effect of these chemical substances on the environment before and during construction but also in the hardened state.

In this paper we focus on the toxicological and physico-chemical properties of the most widely used admixtures in Europe (water reducers and high range water reducers) and their leaching behaviour in recycled concrete. Furthermore a summary of the EFCA Seal of Quality, a tool that specifies environmental criteria for concrete and mortar admixtures is given.

Keywords

Concrete, concrete admixtures, environment, leaching, superplasticizers, concrete demolition material, EFCA seal of quality

Urs Mäder, Product Technology Director Construction Chemicals, SIKA Technology AG, Zürich/Switzerland / Chairman of the EFCA-Environmental Task Group

René Gälli, Deputy General Manager, BMG Engineering AG, Schlieren/Switzerland

Michael Ochs, Group leader, BMG Engineering AG, Schlieren/Switzerland

1. Introduction

Concrete admixtures are used specifically to improve workability and the end quality of the concrete to be obtained. With regulation use of concrete admixtures the pollution of the environment to be expected is very slight so that the products can be rated as environmentally compatible.

2. What are concrete admixtures and why are they needed?

Modern concrete contains in addition to cement, gravel, sand, additive and air normally also one or more concrete admixtures. In this way, depending on the nature of the admixture, it is possible to influence specifically concrete properties such as strength, flow behaviour, resistance to freeze thaw cycles and deicing salts, sulphate resistance, setting characteristics, pumpability and others. According to EN 934-2b a distinction is made between the following categories of concrete admixture (Table 1): The action of superplasticizers is based on long familiar principles. Abram found at the beginning of last century that for a given set of materials and conditions the compressive strength of concrete depends on the proportion of cement in the cement paste. However, as the cement paste consists of cement and water, it becomes clear that the so-called water/cement (w/c) ratio is to be kept low in order to achieve good strength values and durability, for as is well known only a part of the water (25% by weight of cement) can react with the cement, the excess water evaporating leaving behind pores. The w/c ratio thus has a dominating influence on the properties of the green and the hardened concrete. Using plasticizers or rather superplasticizers (SP) makes it easy to achieve this objective. Air-entraining agents, for example, are indispensible for making concrete resistant to freeze thaw cycles and deicing salts. Air voids of a certain size and distribution are deliberately created to act as expansion spaces capable of absorbing the pressure of the freezing water.

TAB. 1: *Classification of concrete admixtures*

Water reducing / Plasticizing
High-range water-reducing / Superplasticizing
Water retaining
Air-entraining
Set accelerating
Hardening accelerating
Set retarding
Water resisting

Ecological demands on concrete and also the continuous adaptation and development of construction and working techniques represent a constant challenge to researchers and developers of concrete admixtures. An "ecological concrete" is a concrete which according to ecological criteria has an optimized composition of the individual components (sand/gravel, cement, water, concrete admixture, additives). A crucial criterion in this is the durability of the concrete exposed to the environment. The latter is positively influenced by the proper use of modern concrete admixtures. In total according to FSHBZ statistics approx 14,000 t of concrete admixtures were sold in Switzerland in 1994, SPs are approx. 75% and they make up the largest part. Today approximately one third of concrete placed has been modified with a concrete admixture.
Environmental pollution from the use of concrete admixtures has been critically questioned in various quarters. This publication summarizes the state of knowledge regarding

environmental pollution caused by the use of concrete admixtures and the effects on man and environment to be expected.

3. Choice of concrete admixtures used for the study

From the different concrete admixtures described above it were superplasticizers (melamine sulphonate polymers and naphthalene sulphonate polymers) that were chosen because of their wide range of uses, the total quantity used in construction and the material properties.

4. Environmental compatibility of concrete admixtures

4.1 Data collection and evaluation

The effects of chemical products on man and the environment are assessed in accordance with the relevant chemicals legislation (1,2,3). All emissions to be expected in the course of the life cycle of a product are covered and assessed with regard to possible effects.

The following procedure has proved itself in practice:

I. Data collection and evaluation
II. Listing of the life cycle
III. Assessment of environmental compatibility
IV. Measures for improving environmental compatibility

Data from safety data sheets, product tests and scientific studies were used as the database. Various data are product-specific so that special test methods were used. In part the investigations were conducted in cooperation with relevant institutes.
(e.g. EAWAG (4) EMPA (5))

A selection of relevant data for the currently most important superplasticizers is summarized in Table 2. All substances are readily soluble in water, have very low octanol/water distribution coefficients (i.e. they do not concentrate in the fatty tissue of organisms) and are not volatile. They are classified in Switzerland as non-toxic and have an acute toxic effect on water organisms only at very high concentrations. They are not easily biodegradable.

TAB. 2: *Summary of most relevant physico-chemical and toxicological properties of superplasticizers used for the chemical risk assessment*

Parameter	**Naphthalene** sulphonate polymer (NSP)	**Melamine** sulphonate polymer (MSP)
Water solubility	>100 g/l	>100 g/l
Octanol/water distribution log Pow	<<-1*	<-4
Toxicity for mammals LD50 rodent (mg/kg)	3400->4000	>4000
Aquatic toxicity fish EC50 (mg/l)	100-2000	560-3200
Aquatic toxicity daphnia EC50 (mg/l)	>220	>100
Mutagenicity in Ames test (bacteria)	negative	negative
Biodegradability OECD 302B test (%)	43	15-51
Water hazard class WHC (Germany)	~ 1	1

* = calculated
LD50 = Dosis at which 50% of the testing animals are killed
EC50 = Water concentration at which 50% of the test animals are showing a particular effect
WHC = Classification: 1 lowest hazard, 3 highest hazard

4.2 Listing of the life cycle

The following stages in the life cycle of concrete admixtures can lead to pollution of the environment:

- Production
- Transport
- Storage/handling
- Use of the concrete admixtures
- Service life of the building
- Recycling of concrete from demolition
- Disposal of building waste and residues.

Figure 1 shows the simplified life cycle of concrete admixtures taking the example of the use of ready-mixed concrete.

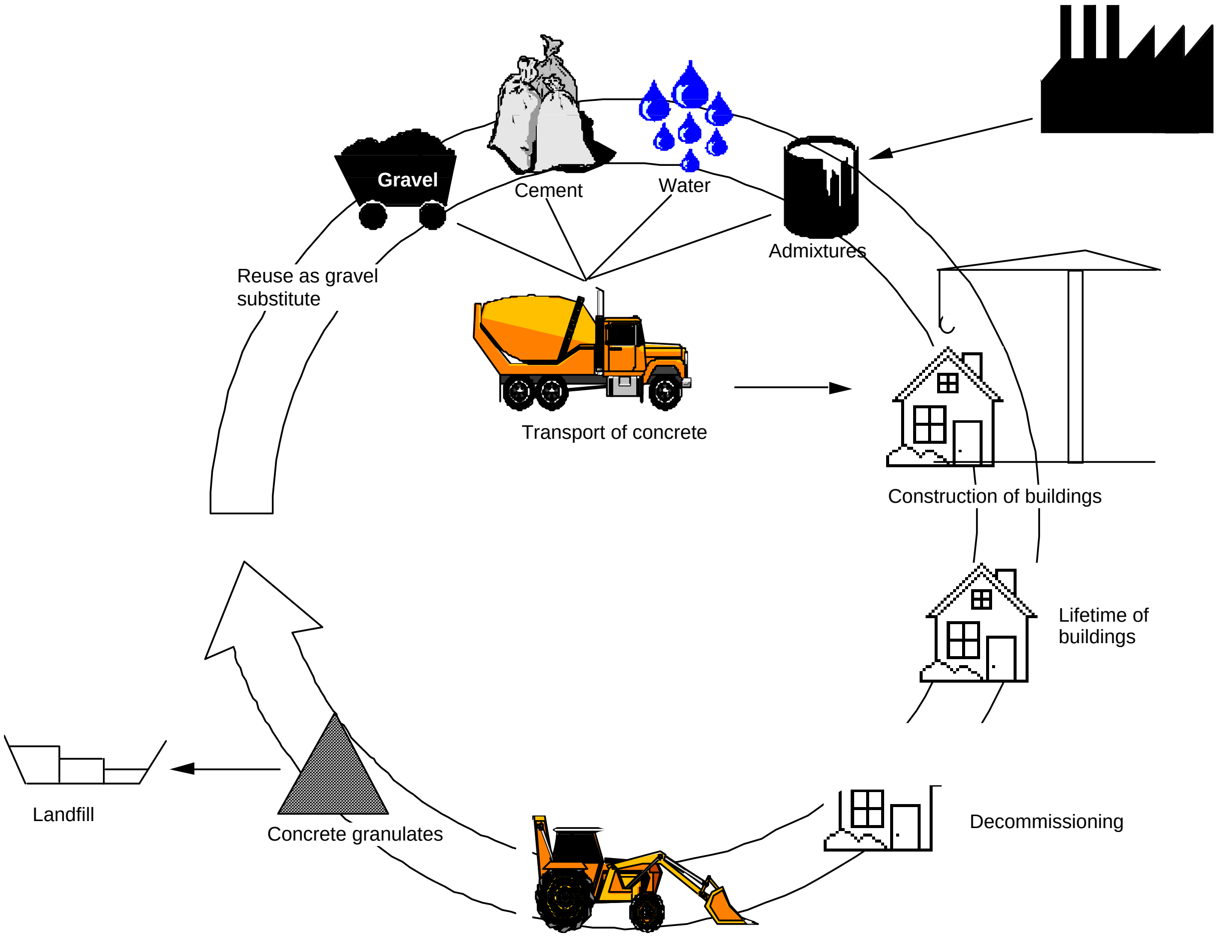

FIG. 1: *Simplified life-cycle of concrete admixture*

4.3 Assessment of environmental compatibility

The burden on man and environment was assessed using the emissions found or estimated for each stage of the life cycle. The toxicological and ecotoxicological characteristics of the concrete admixtures served as a basis for the assessment. (6)

4.3.1 Emissions and mass flows

Pollution from SPs was determined experimentally or estimated for each stage of the life cycle of the products. It was found that environmental pollution can occur above all when using SPs and when storing concrete granulate containing SPs and when using this granulate in road construction.

4.3.1.1 Production

Thanks to specific treatment of waste water with recovery of the substances contained in the waste water only very small quantities of SPs get into public purification plants.

FIG. 2) Storage of admixtures in a tunnel job site in Switzerland

Hook up device — Storage containers

Dosing units — Control room of the concrete plant

4.3.1.2 Use

It can be assumed that when using SPs in producing precast concrete units no relevant emissions occur.
The use of SPs for preparing site mixed concrete is in swift decline. With proper handling the environmental pollution (e.g. washing of implements) is expected to be very slight.

When used for ready-mixed concrete the main focus is on waste disposal from the rinsing of ready-mix trucks. These emissions are strongly on the decline as on the one hand rinsing water is being increasingly used for preparing concrete and on the other retarders can be added to the concrete remaining in the trucks which delay hardening.

4.3.1.3 Emissions from existing structures

EMPA studies on concrete test specimens have shown that SPs do not cause any appreciable emissions of volatile organic compounds (7).

4.3.1.4 Emissions from concrete demolition material

Leaching tests with crushed material (4-8 mm) from defined concrete test specimens have shown that it is not the originally used SPs that are leached but their abiotic degradation products as well a impurities in the original product. Investigation of the leachates from cements containing naphthalene sulphonate polymers showed that not the polymers, but mostly naphthalene sulphonate monomers were leached. These leached monomers are "readily biodegradable" (OECD 302B) and thus much better biodegradable than the original product. Only a fraction of the total amount of SP used could be leached even under the worst-case conditions of laboratory leaching tests with crushed concrete material. It was found that 15-25 % of naphthalene sulphonate polymers, ligninsulphonates and polycarboxylates was leached and 30-60% in the case of melamine sulphonate polymers.

A comparison of the leachability of defined test specimens containing SPs with crushed concrete from recyclers has shown that only part of the organic substance found in the leachate of used concrete material (after demolition) originates from the SP (Fig. 2). A significant part is from other products used in construction such as coatings, adhesives, mastic joint sealers, etc., from foreign materials (wood, gypsum, asphalt, etc.) and the cement itself.

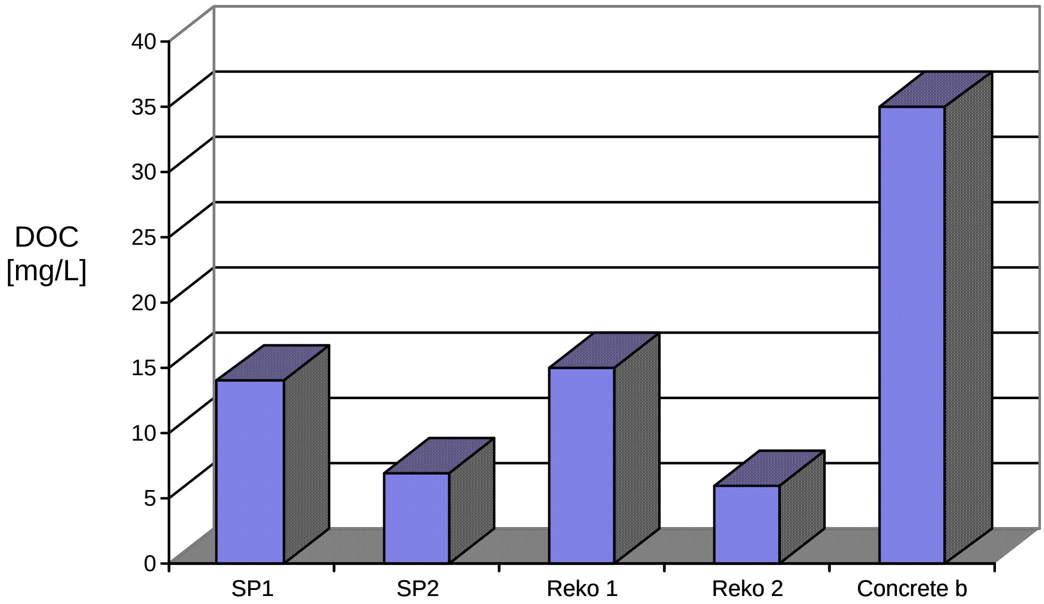

FIG. 3: Dissolved organic carbon (DOC) in eluates from crushed concrete specimens. Specimens which contain only SPs (SP 1 = naphthalene sulphonate polymer, SP 2 = melamine sulphonate polymer) are compared with crushed concrete specimens (Reko 1 and 2) and coated concrete demolition material. SP specimens contain 0.4% active substance in relation to the cement weight.

Concrete demolition material is stored in heaps in the open until it is reused (Fig. 4, Fig.5). As concrete admixtures have only found widespread use in about the last 30 years, it can be assumed that the concrete demolition material currently becoming available should in large part be free of concrete admixtures. In order to be able to estimate future emissions from the leaching of SPs, tests were carried out with test specimens with a defined SP content. If the total quantity of concrete demolition material (SPs at today's batching rate) becoming available yearly in the Canton of Zurich is stored in the open, max. 300 kg of SPs in total can be leached each year by precipitation falling upon it. Similar considerations with the use of concrete granulate in unbound form for road beds (Fig. 2) show emissions of max. 900 kg of SPs per year for the whole Canton of Zurich. These emissions would in the worst case (assumption: there is no degradation) lead to measurable concentrations of organic compounds of max. 0.2 mg/l DOC in the ground water immediately below the heaps and roads in question.

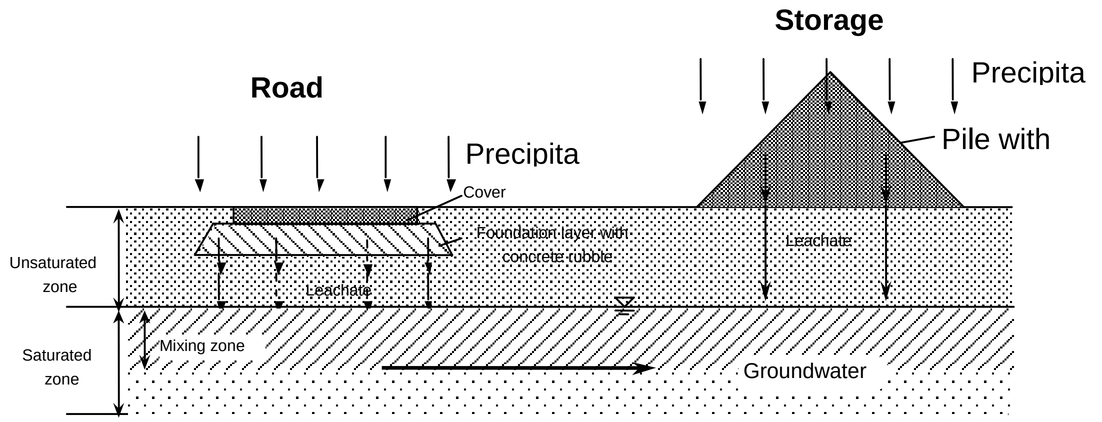

FIG. 4: Typical scenarios with occurrence of precipitation when storing concrete demolition material or granulate (right) and when using processed concrete demolition material as road bed (left).

These estimates are based on very unfavourable assumptions. If one considers, for example, the guidelines issued by the Canton of Zürich for the use of secondary building materials (8) the emissions to be expected should be less by 1-2 orders of magnitude.

FIG. 5: Site for the production of concrete granulate from demolition material of buildings (before the ground was sealed and rainwater was collected and directed to a wastewater treatment facility)

Swiss legislation on waste (TVA, (9)) stipulates that building waste must be recycled if possible. Crushed concrete is mostly used in hydraulically bound form as a substitute for gravel. The question therefore arises of whether an accumulation occurs with the repeated recycling of concrete with the addition of concrete admixtures. Calculations show that at most the content is doubled with a proportion of 70% crushed concrete in the aggregate (assumption: infinite number of recycling).

No problems arising from SPs are to be expected when dumping concrete demolition material as an inert substance in compliance with legislation (TVA).

4.3.2 Risk assessment summary

The mass flows of superplasticizers have been assessed (EFCA, 2001; Fig. 5). On the basis of existing data and estimates the superplasticizers under consideration can hardly be classified as ecologically hazardous from the point of view of environmental technology. With correct use and disposal of SPs no adverse effects are to be expected for
the health of man and environment. As the concrete admixtures are very readily soluble in water, no accumulation is to be expected in soils, water-bearing strata or organisms. The products used as SPs are also used in significantly greater quantities in other sectors. Caution is therefore required in the interpretation of measurement data, for example when it comes to waste water.

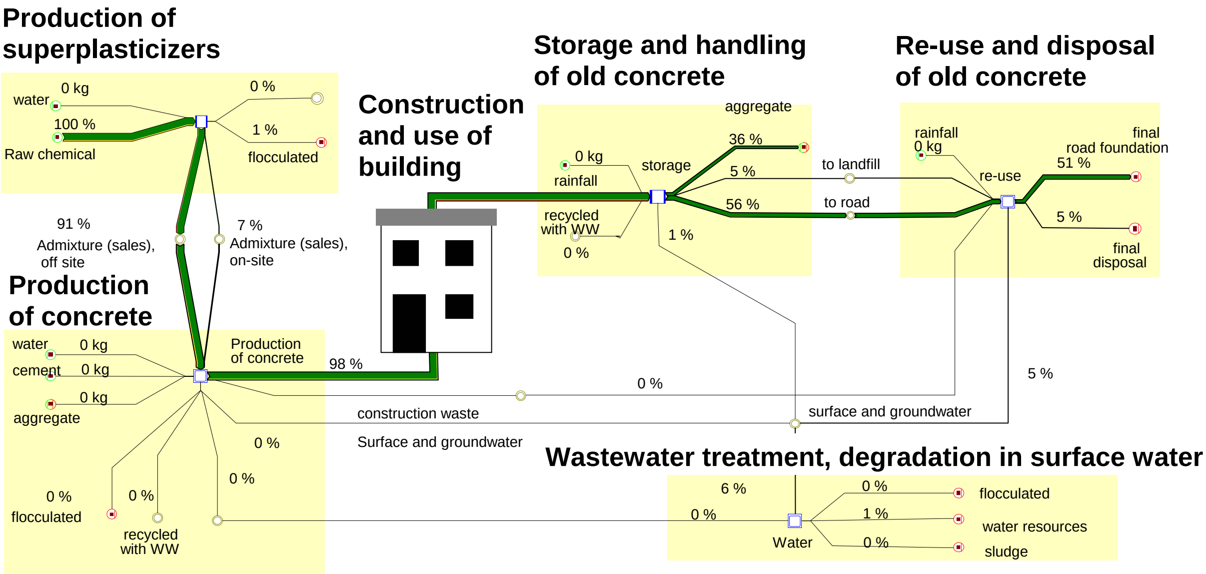

FIG. 6: Mass flow analysis of superplasticizers in Switzerland (worst-case assumptions). The emissions have been calculated for the year 2000 assuming that the recycling of old concrete will not change until the buildings constructed in 2000 will be recycled at the end of their life-time (>2050).

4.4 Measures for improving environmental compatibility

Emissions which lead to significant burdening of the environment must be reduced to a compatible level. In principle a distinction is made between three categories of measure:
• Information and recommendations (e.g. recommendations on on-the-job safety)
• Safety measures (e.g. taking-back of product residues)
• Reduction (e.g. restrictions on use)

In general measures to improve the environmental compatibility of these products should be taken where the greatest emissions are to be expected. In the case of ready-mixed concrete wash water is increasingly being reused as gauging water and unused concrete is being mixed and used again with fresh concrete.
Of the sources of emission discussed here leaching during storage should have the greatest potential effects on the environment. In the context of precautionary measures therefore care should be taken that yards where concrete demolition material is stored are drained and the drained water led off to a purification plant.

The incorporation of concrete demolition material in road foundations should be far less relevant. In order here too to minimize emissions into ground water, the concrete demolition material should as far as possible be used in bound form. This reduces the amount of water infiltrating and thus emissions into the underground.

4.5 EFCA-Seal of Environmental Quality

Based on the above criteria and the European chemical substance legislation [2, 10], a seal of environmental quality for concrete and mortar admixtures has been established [11], which is presently in use in Switzerland, Belgium, The Netherlands, Germany, Norway and France.

The EFCA-Seal of Environmental Quality (abbreviation: EFCA EQ-Seal) specifies environmental criteria for concrete and mortar admixtures. This concerns, in particular, the use of materials and blends that are classified as environmentally relevant. The aim is to minimise the effect on man and the environment arising from the use of concrete admixtures. The EFCA EQ-Seal is awarded to products that have no foreseeable effects on the environment and are therefore classified as environmentally compatible.

Products that carry the EFCA seal of quality fulfil the following requirements:

- They are neither toxic nor damaging to health when properly used.
- They are neither explosive, inflammable nor a fire hazard.
- There are no foreseeable harmful effects on the environment when properly used.
- Building materials that contain products carrying the EFCA seal of quality are inert materials in accordance with Swiss legislation on waste and can be recycled.
- The packaging has been optimized.

5. A look into the future

Even if the database for concrete admixtures can be described as good compared with other products the knowledge gaps still found during this study have been partially closed. The following questions are dealt with in particular:

How quickly do concrete admixtures decompose in concrete?
How is the leaching behavior of concrete admixtures from intact concrete structures?

In another step environmental compatibility is to be balanced against the benefit of concrete admixtures, which will allow an overall assessment of concrete admixtures. New products are in future to be assessed in accordance with the above-mentioned procedure and taking into account the experience gained.

6. References

(1) EU Order 793/93

(2) EC Directives 99/45/EC and 67/548/EEC incl. adaptations and amendments

(3) Swiss Order on ecologically hazardous substances (StoV, 1986)

(4) EAWAG Dübendorf/Switzerland, Swiss Federal Institute for water, waste water and water protection

(5) EMPA Dübendorf/Switzerland, Swiss Federal Materials Testing Institute

(6) FSHBZ. Environmental compatibility of concrete admixtures (1st version 1995)

(7) Federal Office for Energy Management. Pollutant emission behaviour of building materials (1995)

(8) Directorate of Public Buildings of the Canton of Zurich. Guidelines for the ecological use of secondary building materials in superstructure and in subgrade stabilizers of roads, paths and squares.

(9) Swiss Technical Ordinance on Waste (1 July 1994) TVA Technische Verordnung über Abfälle

(10) EC Technical Guidance document 91/155/EEC

(11) EFCA (2001). EFCA-seal of environmental quality for concrete admixtures: Technical Guidelines. Version 2.3. FSHBZ, c/o Sika AG, P.O.Box, Tüffenwies 16, CH-8048 Zurich