Assessment of the environmental compatibility of concrete admixtures

R. Gälli and M. Ochs
BMG Engineering AG, Schlieren, Switzerland

U. Mäder
Fachverband Schweiz. Hersteller von Betonzusatzmitteln FSHBZ c/o Sika AG,
Zurich, Switzerland

ABSTRACT
Concrete and mortar admixtures are substances added to concrete or mortar 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 frost 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 multicomponent system concrete. Nevertheless, it is our task to evaluate the effect of these chemical substances on the environment before and during construction but also in the hardened state.

In this article we focus on the toxicological and physicochemical properties of the mostly used products in Europe (water reducers and high range water reducers) and their leaching behaviour in recycled concrete.

Keywords: concrete admixtures, environment, leaching, superplasticizers, concrete demolition material
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 frost and deicing salts, sulphate resistance, setting characteristics, pumpability and others. According to prEN 934-2 (Final Draft 1994) 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 this 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 (approx. 25%) of the water 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 indispensable for making concrete resistant to frost 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.

German abbreviation

<table>
<thead>
<tr>
<th>Concrete plasticizers</th>
<th>(BV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superplasticizers (SP)</td>
<td>(HBV)</td>
</tr>
<tr>
<td>Air-entraining agents</td>
<td>(LP)</td>
</tr>
<tr>
<td>Accelerators</td>
<td>(BE)</td>
</tr>
<tr>
<td>Retarders</td>
<td>(VZ)</td>
</tr>
<tr>
<td>Integral waterproofers</td>
<td>(DM)</td>
</tr>
<tr>
<td>Emulsifiers</td>
<td>(ST)</td>
</tr>
<tr>
<td>Corrosion inhibitors</td>
<td>(KI)</td>
</tr>
<tr>
<td>Antifreeze agents</td>
<td>(FS)</td>
</tr>
</tbody>
</table>

Table 1: Classification of concrete admixtures

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, whereby the SPs with approx. 75% 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 by 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 was 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. Are concrete admixtures environmentally incompatible?
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

I. Data collection and evaluation
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. EAWAG1, EMPA2). A selection of relevant data for the currently most important superplasticizers is summarized in Table 2.

---

1 Swiss Federal Institute for water, Waste water and Water Protection (EAWAG Diibendorf, Switzerland)
2 Swiss Federal Materials Testing Institute (EMPA Diibendorf, Switzerland)
Table 2: Selection of relevant data for superplasticizers

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Naphthalene sulphonate polymer (NSP)</th>
<th>Melamine sulphonate polymer (MSP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water solubility</td>
<td>&gt;100 g/l</td>
<td>&gt;100 g/l</td>
</tr>
<tr>
<td>Octanol/water distribution Cow (log)</td>
<td>&lt;&lt;-1*</td>
<td>6-4</td>
</tr>
<tr>
<td>Toxicity for mammals LD50 rodent (mg/kg)</td>
<td>3400-&gt;4000</td>
<td>&gt;4000</td>
</tr>
<tr>
<td>Aquatic toxicity EC50 fish (mgA)</td>
<td>100-2000</td>
<td>560-3200</td>
</tr>
<tr>
<td>Aquatic toxicity EC50 daphnia (mgA)</td>
<td>&gt;220</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Mutagenicity in Ames test</td>
<td>negative</td>
<td>negative</td>
</tr>
<tr>
<td>Biodegradability OECD 302B (%)</td>
<td>43</td>
<td>15-51</td>
</tr>
<tr>
<td>Poison category (CH)</td>
<td>free</td>
<td>free</td>
</tr>
<tr>
<td>Water hazard class (D)</td>
<td>~1</td>
<td>1</td>
</tr>
</tbody>
</table>

* = calculated

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.

II. 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.
III. 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.

4.1 Emission 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.

4.1.1 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.

4.1.2 Use
It can be assumed that when using SPs in producing precast concrete units no relevant emissions occur.

The use of SPs for preparing in-situ 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.
4.1.3 Emissions from existing prefab units
EMPA studies on concrete test specimens have shown that SPs do not cause any appreciable emissions of volatile organic compounds [5].

4.1.4 Emissions from concrete demolition material
Leaching tests with broken material (4-8 mm) from defined concrete test specimens have shown that it is not the originally used SPs that are leached but their decomposition products. These are readily biodegradable which is favourable for environmental behaviour. Under the strict conditions of testing a total of some 20-30% of the SPs used were leached. As estimates taking one product showed, more than half of the leached material is present in the form of decomposition products. A comparison of the leachability of defined test specimens containing SPs with concrete granulate from recyclers has shown that only part of the leachable substances come from the use of SPs (Fig. 2). A large part must come from products used in construction (coatings, adhesives, mastic joint sealers, etc.), from foreign materials (wood, gypsum, asphalt, etc.) and the cement itself.

Fig. 2 - List of contents in dissolved organic carbon (DOC) in eluates from concrete specimens (broken material). Specimens which contain only SPs (SP 1 = naphthalene sulphonate polymer, SP 2 = melamine sulphonate polymer) are compared with concrete granulate specimens (Reko 1 and 2) and coated concrete demolition material. SP specimens contain 4% active substance in relation to the cement weight.

Concrete demolition material is stored in heaps in the open until it is reused (Fig. 3). 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 a 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 DOCA in the ground water immediately below the heaps and roads in question.

Fig. 3 - 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 Zurich for the use of secondary building materials [6] the emissions to be expected should be less by 1-2 orders of magnitude.

Swiss legislation on waste [TVA, 7] stipulates that building waste must be recycled if possible. Concrete granulate 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 a doubled content results with a proportion of 70% concrete granulate in the aggregate (assumption: infinitely many recyclings).

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

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.

IV. 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 subgrade.

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 completed. The following questions are dealt with in particular:

How quickly do concrete admixtures decompose in concrete?
How is the leaching behaviour 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.
References

1. EU Order 793/93
2. EU Directive 67/548 incl. adaptations and amendments
3. Order on ecologically hazardous substances (1986)
4. FSHBZ. Environmental compatibility of concrete admixtures (1st version 1995)
6. 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
7. Technical Ordinance on Waste (1 July 1994)