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Waste Materials in Construction: Putting Theory into Practice

Influence of Concrete Technical Parameters on the Leaching Behaviour of Mortar and Concrete

I. Hohberg and P. Schiessl

Institute for Building Materials Research (ibac), Aachen University of Technology, Germany

Abstract

The main aspect in respect to environmental compatibility of cement-based materials, is the leaching environmentally relevant substances. Realistic leaching tests were carried out in order to examine the influence of mortar and concrete technical parameters on leaching. It could be shown that the leaching of heavy metals from cement-based building materials, with and without the addition of fly ash, is independent of the total amount of these components in the building material. Especially, the age of the samples has an influence on the leaching rates. Generally, the emissions from the mortar and concrete samples investigated were very low.

1 Introduction

The main aspect in respect to environmental compatibility of cement-based materials, is the release of inorganic compounds (e.g. heavy metals salts) due to the contact with water e.g. rain or groundwater.

The leaching of environmentally relevant substances from cement-based building materials is often a diffusion dominated process /2/. The release due to diffusion, the diffusion rate for the individual ions/substances can be determined in practice-related leaching tests (tank tests) by investigating the time-dependent leaching behaviour. The diffusion rates allow an assessment of the success of the immobilisation of environmentally relevant substances by a cement matrix. A detailed description on leaching mechanisms and test methods is given in /2, 3/.

The following influencing parameters are to be considered with respect to concrete:

- the porosity and pore structure/density of the concrete
- the degree of hydration and the age of the concrete
- the carbonation

The type of cement and the use of concrete additions like e. g. fly ash and silica fume as well as the water/cement-ratio should have an influence on the leaching behaviour, since they lead to a distinct change in the pore structure of the concrete /3, 4, 5/. In addition to this, the compaction, the curing, as well as the achieved degree of hydration are also of importance. The carbonation (the reaction of calcium hydroxide with the carbon dioxide from the air) of the cement matrix lowers the pH value of the pore solution. Environmentally relevant substances which had been immobilised can probably dissolve, and thus become available for the leaching processes /2/.

2 Investigations

2.1 Materials and methods

The investigations described in this paper were carried out in order to investigate the influence of concrete technical parameters on the leaching behaviour of heavy metals from cement-based materials with and without the application of industrial by-products. The following concrete technological influences were investigated:

- type of cement (normal Portland cement (PC) and blast-furnace slag cement (BFSC)),
- type of addition (addition of fly ashes with different heavy metal contents),
- w/b-ratio (w/(c+0.5f)=0.4, 0.5, 0.6),
- age of the samples (90 days, 180 days and 360 days).

A normal portland cement (PC) and a blast-furnace slag cement (BFSC) in compliance with the requirements of German standard DIN 1164 were selected for the investigations. Four bituminous coal fly ashes (FA) with different heavy metal contents were chosen as concrete addition. For the investigations mortar mixtures with and without addition of FA were prepared according to European standard EN 196-1. The fly ash content (f) in the mixtures with FA was 20 mass.% in relation to the total binder content (c+0.5f). Mortars with different w/b were produced. Additionally, concrete mixtures with and without addition of FA were prepared. The grain size distribution of the concrete aggregates corresponded to grading curve A/B 16 in accordance with the German standard DIN 1045. The w/b was 0.5 for all concretes. Mortar specimen (40 by 40 by 160 mm) and concrete cubes (100 by 100 by 100 mm) were produced from the mixtures. After one day in the mould, the specimen were cured until the investigations in a climate chamber at 20 °C and 95 % relative humidity.

Tank leaching tests similar to that described in the Dutch standard NEN 7345 with a duration of 56 days and 8 leachant renewals were performed with the mortar specimen and the concrete cubes.

2.2 Results and discussion

The results from the tank leaching tests with the mortar and concrete specimen are summarised in table 1. Generally, the amounts of heavy metals leached are very low, often near the detection limits, due to the immobilisation of the heavy metals in the highly alkaline, dense cement matrix. The addition of fly ashes with relatively high contents of heavy metals does not result in higher emissions. Due to the pozzolanic reaction and the filler effect of the fly ashes the emissions from mortar with fly ashes are often lower than those for the mortars without fly ash addition (especially for zinc).

The leaching results from the mortars are represented for zinc in dependence on the total zinc content in Fig. 1. The total zinc content was each divided into the fraction from the aggregate, the cement and the fly ash that were calculated based on the composition and the contents of the ingredients.

Table 1: *Tank leaching results from the investigations of mortars and concrete in dependence on cement and fly ash addition (w/b =0.5; f/c=0.25) /2, 3/*

material	mortar								concrete			
cement	PC					BFSC			PC			BFSC
addition	-	FA1	FA2	FA3	FA4	-	FA1	FA2	-	FA1	FA2	-
parameter	total amount leached in mg/kg[1)]											
Arsenic, As	< 0.01								< 0.02		0.02	0.02
Cadmium, Cd	< 0.01								< 0.02			
Chromium, Cr	0.09	0.15	0.03	0.03	0.07	0.08	0.09	0.10	0.02	0.09	0.04	0.05
Copper, Cu	< 0.01	< 0.01	0.01	0.02	0.01	< 0.01	< 0.01	< 0.01	0.02	0.02	0.02	< 0.02
Lead, Pb	0.01	0.03	< 0.01	0.02	0.02	0.03	< 0.01	< 0.01	< 0.02	< 0.02	< 0.02	< 0.02
Nickel, Ni	< 0.01								n. d.			
Zinc, Zn	0.18	0.09	0.07	0.09	0.11	0.02	0.02	<0.02	0.13	0.04	0.04	0.04

1) leached amounts after 56 days and 8 leachant renewals

PC: normal portland cement; FA : bituminous coal fly ash; BFSC: blast-furnace slag cement

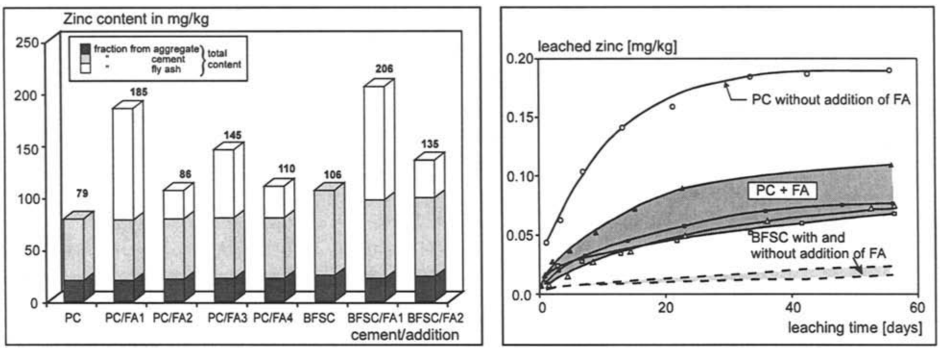

Fig. *1: Tank leaching test results in relation to total zinc contents for different mortars in dependence on cement and addition (PC: portland cement; FA: fly ash; BFSC: blast-furnace slag cement; w/(c+0.5f)=0.5 for all mortars) /1/*

The amounts of zinc leached in the tank tests are, for mixtures with addition of fly ash, inspite of higher total contents, less than those of the corresponding mixtures without fly ash. This applies to the mortars as well as to the concretes. This effect can be attributed to the immobilisation of zinc due to the formation of insoluble complex salts. The diffusion of zinc in the leachant is, in addition to this, impaired due to the compacting effect of the fly ash. The amounts of leached zinc are especially low for blast-furnace slag cement mortars. The zinc is presumed to be fixed in the glassy matrix of the blast-furnace slag and thus cannot be mobilised.

Fig. 2 shows the tank leaching results from mortar specimen for chromium. The influence of the fly ash addition is not as distinct as for zinc. The chromium amounts leached for mortar with fly ash FA1 lie above the value for the mortar without the addition of fly ash. Fly ash FA1 has a high fraction of soluble chromium compared to the other fly ashes /2/. A decrease in the amount of leached chromium can be recognised in the other mortar mixtures with fly ash. This can also be attributed to the compacting effect of the fly ash.

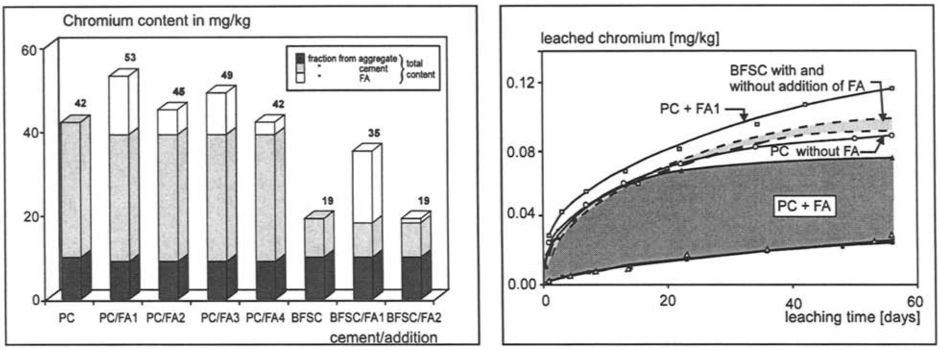

Fig. 2: Tank leaching test results in relation to total chromium contents for different mortars in dependence on cement and addition (PC: portland cement; FA: fly ash; BFSC: blast-furnace slag cement; w/(c+0.5f)=0.5 for all mortars)

The amounts of leached chromium from the mixtures with blast-furnace slag cement are rather high compared to the total and available chromium content. The reason may be a reduction in the pH value of the pore solution due to the large content of blast furnace slag. This effect does not occur with zinc, since zinc has its minimum solubility at pH values around pH=10.

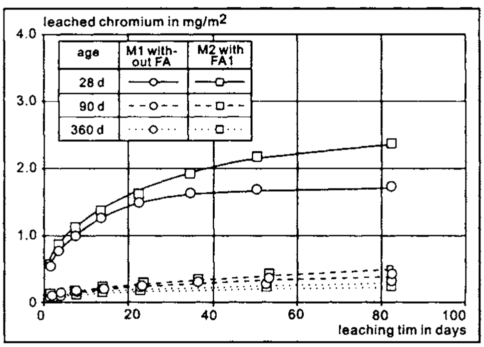

Fig. 3: Results from tank leaching tests; leaching behaviour in dependence on the age of the samples

In Fig. 3, the leaching behaviour of chromium for mortars with and without addition of fly ash is shown in dependence on the age of the samples. As expected, the leached amounts decrease with increasing age of the samples. The influence of the hydration age occurred in the same manner for the other elements /2/.

2.3 Determination of emissions

The release of heavy metals from cement-based building materials is mainly controlled by diffusion. In order to be able to compare and assess the results from tank tests, the heavy metal amounts which were released due to diffusion (emission after 365 days) were calculated from the test results (details of the calculation see /2, 3/).

The results of the calculations for the investigated mortars and concretes with the examples of zinc and chromium are represented in Fig. 4. The following can be taken from the results:

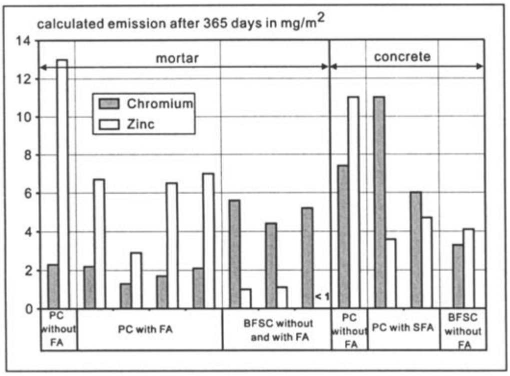

Fig. 4: Chromium and zinc emissions from mortars and concretes in dependence on type of cement and addition (PC: cement; BFSC: blast-furnace slag cement; FA: fly ash; w/(c+0.5f)=0.5)

- Smaller emissions due to diffusion were yielded for the PC mortars with addition of fly ash in relation to that without fly ash addition. This can be attributed to the filler effect of the fly ash and to a compaction in the pore system due to the pozzolanic reaction. This leads to a hindering in the diffusion process. All fly ashes had a diffusion hindering influence on the metals zinc, copper and lead /2, 6/. The influence was not so clear in the case of chromium.
- The chromium emissions calculated for the mortars made of blast-furnace slag cement are larger than those for portland cement mortars, whereas only very small amounts are released for the heavy metals zinc, copper and lead. The addition of fly ash does not have a strong influence on the release rates. This can be explained by the fact that the use of blast-furnace slag cement strongly reduces the release rates. The additional effect of the fly ash is not noticeable.
- The emissions calculated are generally larger for concretes than for mortars. This could be attributed to the higher porosity of the hardened cement paste in the contact zone areas between aggregate and hardened cement paste. This effect is more distinct for concrete, because of its higher fraction of contact zones, than it is for mortar. Another possible explanation is the smaller fraction of cement matrix resulting in lower pH values in the leachates.

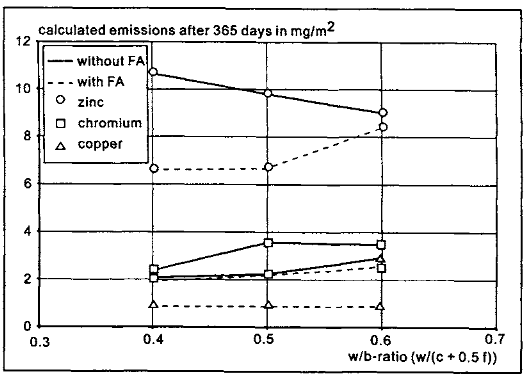

Fig. 5: Emissions from mortar with and without addition of fly ash in dependence on water/binder-ratio

In Fig. 5, the emission in dependence on water/binder-ratio are represented for mortar with and without addition of fly ash. Fig. 5 shows no distinct influence of the w/b-ratio on the emissions. The emission is partly reduced with higher w/b ratios (contrary to what was expected). This is attributed to higher dissolution of other ions (like calcium) which lead to a precipitation of the heavy metals. Generally the leached amounts are very low, therefore, the influence of the w/b-ratio could not be deduced. For main elements like sodium or potassium, the emission increase with increasing w/b-ratios /2/.

3 SUMMARY

The results represented here have shown, that the leaching of heavy metals from cement-based building materials, with and without the use of fly ash is largely independent of the total amount of these constituents in the building material. The immobilisation of the substances considered and the density of the cement matrix are decisive in the leaching. Generally the emission of heavy metals from the mortars and concretes investigated were very low. The addition of fly ashes reduces in most cases the leaching rates, especially for zinc. The w/b has no distinct influence on the leaching of heavy metals. Higher ages of the cement-based materials and thus the hydration grade lead to lower leaching rates.

4 References

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