Penetration of degradation products from adhesive into concrete

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ABSTRACT
This study shows that components in a damp floor construction may begin a degradation process and form volatile decomposition products. These decomposition products may be emitted into indoor air and migrate into the subfloor. VOCs in the sub floor may be stored there for a long time and may eventually be emitted into the indoor air.

The specimens in the study are designed to represent a small part of a floor construction with devices for sampling VOCs in the concrete at different distances from the surface. The results of the measurements show that a large quantity of VOCs may be emitted from a newly bonded PVC flooring on a moist concrete floor. They also demonstrate the rate of penetration of the degradation products from the adhesive into a subfloor of concrete, and the quantities involved.

INDEX TERMS
Concrete floors, degradation of adhesive, contamination distribution, measuring technique, VOCs.

INTRODUCTION
One of the most important sources of enhanced VOC in the Nordic building stock are moisture-damaged floorings (Kumlin et al., 1994; Hall, 2003; Engström and Sjöberg, 2002; Sjöberg and Nilsson, 2002). Many studies show that these constructions can have a direct health effect (Haverinen, 2002; Norbäck et al., 2000; Tuomainen, Seuri and Sieppi, 2002). VOC that are formed below the flooring during alkaline hydrolysis of flooring adhesive can migrate into surrounding materials (Sjöberg, 1999; 2000; 2001). They may migrate upwards through the flooring and escape into the room air, and they may also migrate down into the concrete and be stored there for a long time.

An analytical model for these transport processes has previously been developed at Chalmers University of Technology and presented in Sjöberg (2000; 2001). The analytical model is based on a qualitative model in which alkaline moisture and acrylate copolymer are two critical components for alkaline decomposition of flooring adhesive. The way moisture distribution in the concrete slab is affected by moisture increment from the adhesive is illustrated at the left hand side of Figure 1.

However, it is not enough for the concrete to be either alkaline or moist, both conditions must be satisfied simultaneously, and to a sufficient degree, for the substrate to react with the adhesive. If these conditions are satisfied, decomposition, alkaline hydrolysis of the adhesive, takes place and decomposition products are formed.

These decomposition products, OC (organic compounds), can then be transported away. Depending on the properties of the adjoining materials, they are transported to different extents both upwards and downwards. The quantity that migrates down into the concrete, OCIC (organic compounds in concrete), can become bound there and later, when conditions at the surface change, it can migrate upwards again and escape into the air.

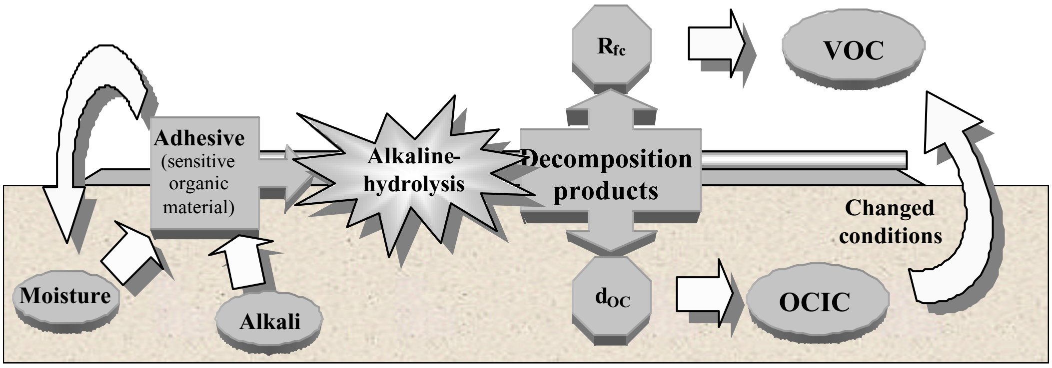

Figure 1. Block diagram of the qualitative model of moisture introduced alkaline decomposition of flooring adhesive.

Method

In the project, a special test specimen was constructed in order to verify the model described above. That is to say, to verify that the adhesive is decomposed at a high moisture level and that decomposition products are then formed which both escape upwards through the flooring *and* penetrate down into the concrete. The specimen was constructed so as to represent a complete floor construction with a PVC flooring directly bonded to a subfloor of concrete. The formwork was made of stainless steel, and both normal structural concrete and self desiccating concrete were used in the investigation. The concrete cast in the formwork was then allowed to dry to approximately 96% RH before a 2 mm thick PVC flooring was bonded using a water based latex adhesive of acrylate type.

The specimen was designed so that the measuring cell FLEC could be placed on top of the flooring on the concrete surface for continuous measurement over almost one year of the decomposition products which are emitted upwards through the flooring. Measuring tubes for measurement of the concentration of decomposition products at three different depths, 5, 10 and 25 mm, were also cast into the concrete; see Figure 2. The internal diameter of the measuring tube is 6 mm and its total length 360 mm. The air in the tube (10.2 ml) is in communication with the pore system in the concrete through a number of holes of 1 mm diameter drilled into the top of the tube.

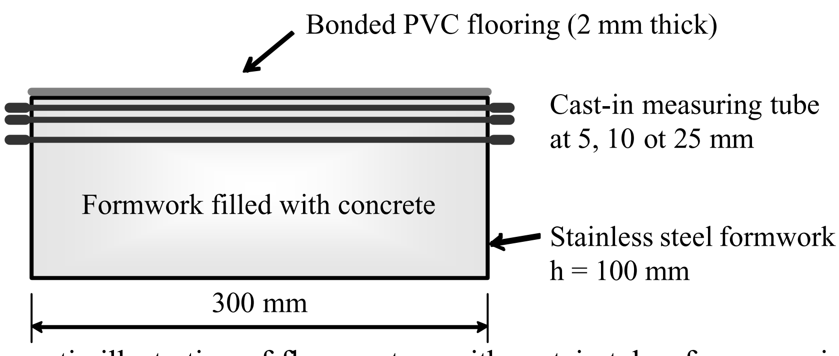

Figure 2. Schematic illustration of floor system with cast-in tubes for measuring organic compounds in concrete OCIC (stored decomposition products from the adhesive)

Measurements

Measurements of the decomposition products which are emitted upwards through the flooring and those which penetrate down into the concrete were carried out on a number of occasions on the test specimens. The first measurement was performed approximately one month after the flooring was laid, and the last measurement was made after almost one year. During the whole investigation the specimens were stored in a controlled climate room at a constant temperature of 20°C and humidity of 50% RH.

Emission from the surface

The measuring cell FLEC and TENAX tube were used during measurements of emission from the surface and the subsequent analysis with GC-FID. At the time of measurement the specimens were conditioned for 24 hours before samples were taken. During conditioning, the FLEC was placed on the surface of the material with a constant air flow of 100 ml/min. The air was taken from a gas cylinder and was brought to approximately 50% RH during both conditioning and measurement.

For sampling, a TENAX tube was connected to the discharge opening of the FLEC with a teflon tube, and 25 ml/min was pumped in for 4 minutes. The procedure during sampling is described in detail in Sjöberg (2001).

Migration down into the concrete

During measurements of the concentration of decomposition products which had migrated down into the concrete, an air sample was taken from the cast-in measuring tubes with the help of the TENAX tubes. This was followed by analysis with GC-FID, i.e. a gas chromatograph equipped with flame ionisation detector.

At the time of measurement, the swage lock coupling on one side, on the lowest measuring tube, was replaced by a carbon tube which was connected to a swage lock coupling of the appropriate size. See the couplings marked in Figure 3. The swage lock coupling on the other side of the same tube was then replaced by a TENAX tube which was connected to a swage lock coupling of the appropriate size. A 20 ml syringe was connected to the TENAX tube with a teflon tube.

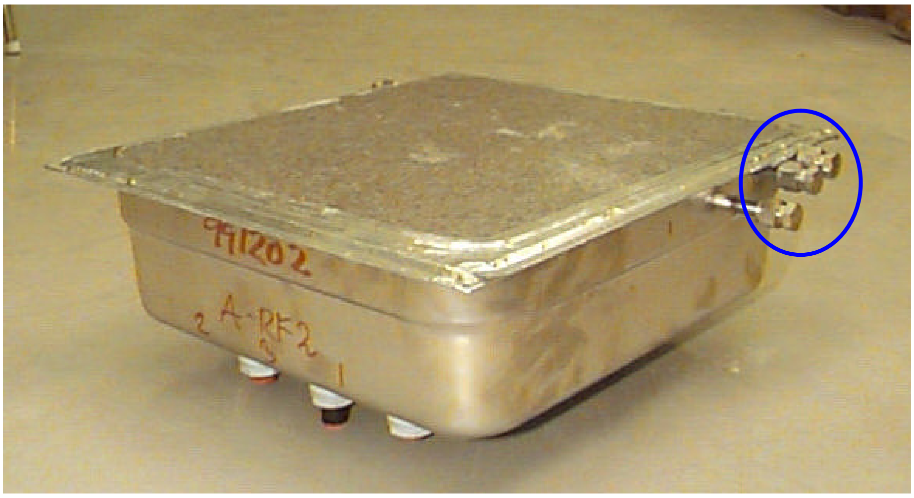

Figure 3. Floor system for long term measurements of alkaline hydrolysis of the floor system. The measuring tubes for VOC profiles were sealed with swage lock couplings at both ends between the measurements.

10 ml of air in the tube was then drawn out through the TENAX tube. Sampling and analysis of the TENAX tube were performed from the bottom up, on one specimen at a time, i.e. with the bottom tube (low concentration) first and the top tube (highest concentration) last. However, the first measurement series, at an age of about 30 days, was performed in the reverse order, i.e. with the top tube first and the bottom tube last.

Measurement uncertainty
No complete investigation of the measurement uncertainty was performed in the study. The uncertainty in measuring the decomposition products can however be estimated to be of the order ±20-30% of reading.

RESULTS
All the measurements on the two test specimens in this study are summarised in Figure 4-7.

The results of measurements of emission from the surface over about 1 year are set out in Figure 4 and 5. The curves in the figures represent the approximate process of emission of n-butanol and 2-ethylhexanol from the surface in long term tests. Figure 4 shows the results from the floor system with normal structural concrete, and Figure 5 the results with self desiccating concrete.

Figure 6 and 7 set out the results of measurements over about 1 year of the concentration of n-butanol down in the concrete. The curves in the figures represent the approximate change in the concentration of n-butanol at distances of 5, 10 and 25 mm from the surface in long term tests. Figure 6 shows the results from the floor system with normal structural concrete, and Figure 7 the results with self desiccating concrete.

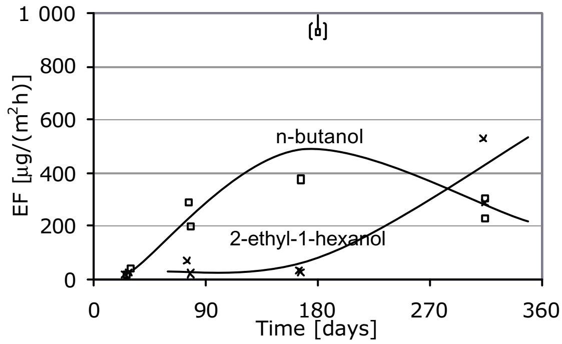

Figure 4. Emission from surface of normal structural concrete.

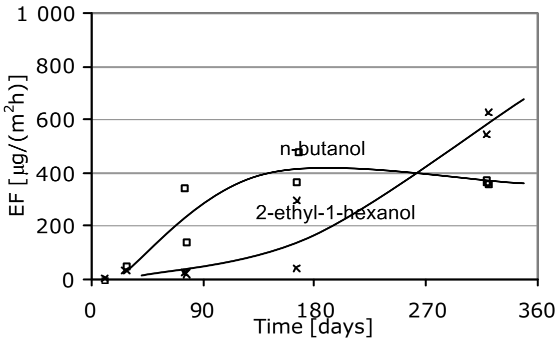

Figure 5. Emission from surface of self-desiccating concrete.

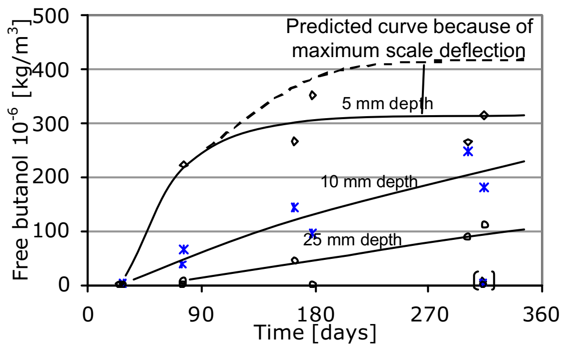

Figure 6. Concentration in normal structural concrete.

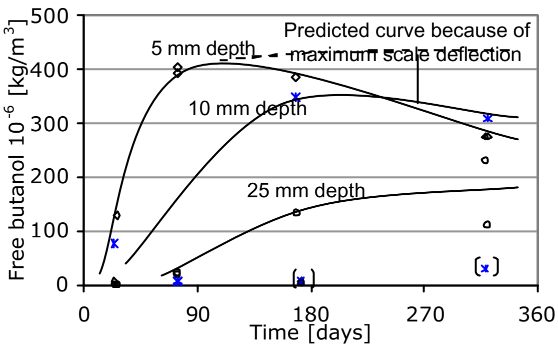

Figure 7. Concentration in self-desiccating concrete.

The dashed curves which show the concentration of n-butanol in the concrete represent the process that can be reasonably expected at a depth of 5 mm. The values shown as plots in the diagrams are at certain times too low, since the FID gave a maximum scale deflection during analysis of the TENAX tubes.

EVALUATION

When alkaline degradation of the adhesive occurs, decomposition products are formed underneath the flooring. The concentration of these chemical compounds soon becomes very high in the region where decomposition takes place. Since nature endeavours to equalise differences in concentration, these decomposition products are transported to nearby regions where concentration is lower. Since decomposition in most cases occurs underneath the whole flooring, the direction of this transport process is mainly vertical, i.e. upwards into the room air and downwards into the concrete.

The rate of this transport is determined by Fickian treatment of the difference in concentration and by using the flow resistance of the intermediate material. In this case the intermediate material is the flooring for transport up into the air, and concrete for transport down into the concrete.

According to the theory described by Crank (1975), the measured flow through the flooring can be related to the concentration below the flooring through Fick's first law. See Figure 8.

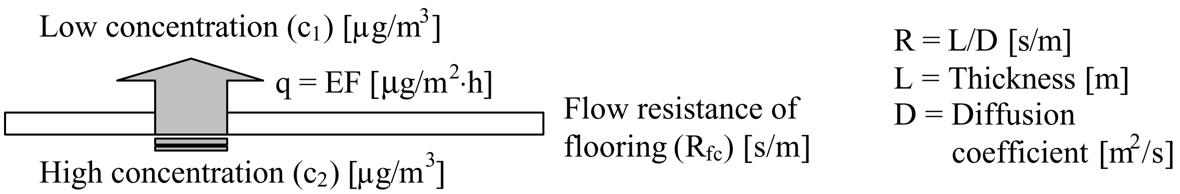

Figure 8. The flow q through the flooring can also be expressed by) EF (emission factor) and is a function of the difference in concentration on the two sides of the flooring and the density of the flooring.

According to Sjöberg (2001), the flow q through the barrier layer can be written as

$$q = \frac{(c_2 - c_1)}{R_{fc}}$$

q	= Flow through the material
c_1	= Low concentration
c_2	= High concentration
R_{fc}	= Resistance, floor covering

Another way of expressing the flow through the surface is by using the emission factor EF. With the units µg/m^2·h, this is equal to 0.3·10^{-12} kg/m^2·s. With R_{fc} = 3.7·10^6 s/m according to Sjöberg (2001), the flow q and concentration c_2 can be calculated for different emission factors EF. See Table 1 below.

Table 1 Calculated concentration under the flooring (c_2) for different flows EF from the surface. Resistance of floor covering R_{fc} according to Sjöberg (2001).

EF	200	400	600	800	1000	µg/(m^2 ?h)
q	55.6	111	167	222	278	10^{-12} kg/(m^2 ?s)
R_{fc}	3.7					10^6 s/m
c_2	206	411	617	823	1028	10^{-6} kg/m^3

DISCUSSION

The measurements in this investigation verify the theory described in the introduction. The investigation demonstrates that application of adhesive to a moist floor slab can give rise to chemical decomposition of the floor materials, and that part of the decomposition products are emitted from the surface of the floor while another part penetrates into the construction where it may persist over a long period.

According to Table 1 in the evaluation, it is very likely that a concentration of 400 g/m^3 free n-butanol in the pores of the concrete gives rise to an emission of the order 400 μg/(m^2·h) from the surface. This is in very good agreement with the measured values.

The method used can, if developed further, assist the makers of flooring materials in determining the critical moisture levels for the decomposition of different kinds of adhesive and floorings. These limiting values are required for a more reliable construction process, where each week that the concrete takes to dry is very expensive.

ACKNOWLEDGEMENTS

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