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Secondary emissions from alkali attack on adhesives and PVC floorings

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Summary

The report describes three investigations of emissions from alkali attack on adhesives and floorings. The investigations show that low alkali levelling compounds, based on calcium aluminate cement, can act as a protection against secondary emissions of 1-butanol and 2-ethylhexanol, provided that the humidity does not exceed a critical level, which with some safety margin is recommended to be 90% RH.

Five tested levelling compounds all had the same principal behaviour. A minimum thickness of the levelling compound is recommended to be 5 mm, although the investigations show that the levelling compounds also had protection capacity at 2 mm.

One way of assuring that the humidity is below the critical level is to use self-desiccating concrete. A concrete with water-binder ratio of 0.43 together with a levelling compound proved effective.

Sammanfattning

Rapporten beskriver tre undersökningar av emissioner orsakade av alkali angrepp på lim och golvbeläggningar. Undersökningarna visar att låg-alkaliska avjämningsmassor baserade på aluminatcement kan utgöra ett skydd mot sekundära emissioner av 1-butanol och 2-etylhexanol, förutsatt att fuktigheten inte överstiger en kritisk nivå, som med en viss säkerhetsmarginal rekommenderas vara 90% RF.

Fem provade avjämningsmassor hade alla samma principiella beteende. En minsta tjocklek hos avjämningsmassorna rekommenderas vara 5 mm, även om undersökningarna visar att avjämningsmassorna också hade skyddsförmåga vid 2 mm tjocklek.

Ett sätt att säkerställa att fuktigheten understiger den kritiska nivån är att använda s k byggfuktfri betong. En betong med ett vatten-bindemedeltal på 0,43 tillsammans med en avjämningsmassa visade sig fungera väl.

Preface

This report gives the details from three investigations of emissions from alkali attack on adhesives and floorings. Johan Alexanderson has published some of the results previously in Swedish journals, but on my initiative he wrote this report to make all the details from the experiments available.

The report is published in our research report series since Johan Alexanderson’s work is close to some of the research being done at the division of Building Materials at Lund Institute of Technology and we are continuously having discussions on these matters. Additionally, once he defended his PhD-thesis at the division.

Lars-Olof Nilsson
Head of the division of Building Materials at Lund Institute of Technology

1 Introduction

The present report summarizes three separate investigations on emissions caused by alkali attack on adhesives and PVC floorings. A common feature of the investigations is that a comparison has always been made between adhering the flooring directly to concrete and adhering it to a levelling compound on top of the concrete. The background to this is that many earlier investigations (1 – 13) have demonstrated the beneficial effect of a low alkali levelling compound, with respect to the aggressiveness on adhesives and floorings.

Another common feature is that the emissions have been studied over long time exposure – minimum two years from the time of adhering the flooring, and in some cases four years. The reason for this is that earlier investigations have shown that the character and the extent of emissions can change considerably over time.

The investigations have been called “A”, “B” and “C”. In investigation A, focus has been on different moisture levels in the concrete, from 86 % RH to 96 % RH. These tests have been carried out using two commercial levelling compounds. Investigation B also used two different levelling compounds at high humidity - 95 % RH - but in this case the two compounds only differed with respect to their binder system. And in the third investigation, C, the effect of using self-desiccating concretes as substrate was studied.

2 Methods

2.1 Specimens

All specimens for emission measurements were cast in cylindrical, stainless steel bowls with an inner diameter of 240 mm and an inner height of 100 mm. The concrete has either been cast to the full height of the container, or a space has been left for the levelling compound (2 or 5 mm thickness). In addition, separate 100 mm thick specimens were cast for measurement of the relative humidity. They were treated in the same way as the emission specimens.

Specimens were prepared at the Swedish Cement- and Concrete Research Institute, at the laboratory of AB Betongindustri and at the author´s laboratory in Djursholm.

2.2 Concretes

The concrete quality and the drying conditions before the application of the flooring varied in the different investigations, as shown in Table 1. The water exposure was used to simulate rain on a building site. The curing conditions in investigation A were varied in order to achieve different relative humidity in the samples (approximately 85 –95 % RH). In investigation B a relative humidity of approximately 95% was sought for. In investigation C self-desiccating concretes with different water/binder ratios created different humidity.

The cement used was from Slite, either ordinary Portland cement type Cem I, or a blended cement type Cem II .

Table 1. Concrete qualities and drying conditions

Investigation	**Water-binder ratio**	**Approx cement content Kg/m^3**	**Initial drying Days**	**Water exposure Days**	**Second drying Days**	**Cement type**
A	0.7	290	28	7	1 ; 14 ; 28	Cem I
B	0.62	330	0	28	7	Cem II
C	0.34 0.38 0.43	520 480 420	0	28	14	Cem II
REF	0.5	510	14	-	-	Cem II

In table 1, also a reference concrete (REF) is included. It is the one that is used in the Swedish Industrial Standard for assessing emissions from composite floor structures (14). Such specimens were included in investigation B and C.

2.3 Levelling compounds

The levelling compounds used are shown in Table 2, together with the thickness and the drying times. The levelling compounds are commercial products from maxit AB (formerly Optiroc AB). The main binder is calcium aluminate cement (CAC) combined with calcium sulphate. In some of the products (ABS 148 and ABS 155), the products also contain ordinary Portland cement (OPC), which is not the case for Strå Universal. The product ABS 3100, which was under development at the time of the tests, was tested with two formulations, either without OPC or with a combination of CAC and OPC. In the latter case, the OPC content was 35% of the total cement content.

The drying times for the levelling compounds are included in the concrete drying times. An acrylic primer, diluted 1:3, was used in all cases before applying the levelling compound.

No levelling compounds were used on the reference concrete.

Table 2. Levelling compounds

Investigation	Levelling compounds	Thickness, mm	Drying time, days
A	ABS 148; Strå Universal	5	7*
B	ABS 3100 (with or without OPC)	2 or 5	1
C	ABS 148	5	7
C	ABS 155	2 or 5	1

*Except specimens with 1 day drying time.

2.4 Adhesives and flooring

All three investigations used the reference adhesive (based on butyl acrylate) and the reference flooring (homogenous PVC) from the Swedish Industrial Standard for measuring the emissions from composite floor structures (14). Descriptions of the reference materials are given in Tables K and L of the Annex.

In addition, a commercial adhesive (Cascoproff 3448, based on copolymers of butyl acrylate and ethylhexyl acrylate) and a commercial PVC flooring (2 mm Tarkett Eminent) were used in investigations B and C.

The floorings were applied at the end of the second drying period according to Table 1, as well for the emission specimens as for the specimens for measuring the relative humidity. The adhesive was applied evenly over the surface with a brush and the flooring was laid down within 2 minutes.

2.5 Emission measurements

The Swedish National Testing and Research Institute (SP) performed all emission measurements using the FLEC-method(15). The results are given as total volatile organic compounds (TVOC) and the alcohols 1-butanol and 2-ethyhexanol, which are the result of alkaline degradation of adhesives and flooring. All emissions are expressed as toluene equivalents. Individual components that are not associated with degradation are not given explicitly, except for one component (2-butanon), but are included in the TVOC-value. SP states that the uncertainty of the FLEC-measurements is ± 15%.

The first emission measurement was done half a year after the flooring had been applied. Then successive measurements were done after 1, 1.5, 2, 3 and 4 years (somewhat different in the different investigations). A view of the emission measurement set-up is shown in Figure 1.

Figure 1 Measuring the emission from combined specimens with the FLEC method.

2.6 Moisture measurements

The moisture measurements were done in the following way. Approximately 10x10 mm flooring was cut out and then a steel tube with a rubber stopper was glued with epoxy around the exposed substrate. The stopper was replaced by an RH-probe connected to a Protimeter dew point instrument, see Figure 2. The reading was taken when equilibrium had occurred, at least one day later. The Protimeter was calibrated regularly with salts at different relative humidity. The accuracy of the RH-measurements is estimated at ± 2% RH.

The first measurements were done for the separate RH-specimens half a year after the application of the flooring, which was the time when the first emission measurements were done at SP on the emission specimens. When the emission measurements were terminated at SP, some of the specimens of investigation C were measured for relative humidity according to the normal procedure at SP, which involves cutting the PVC flooring and inserting a Vaisala humidity probe under the flooring. After that measurement, the cut PVC was sealed with tape and the specimens were sent back to the author's laboratory in Djursholm together with those emission samples that had not been tested for RH at SP. In Djursholm, the specimens were tested for RH according to the described method with the steel tube.

The emission specimens were weighed at SP at different time intervals, in order to measure the weight loss through the flooring.

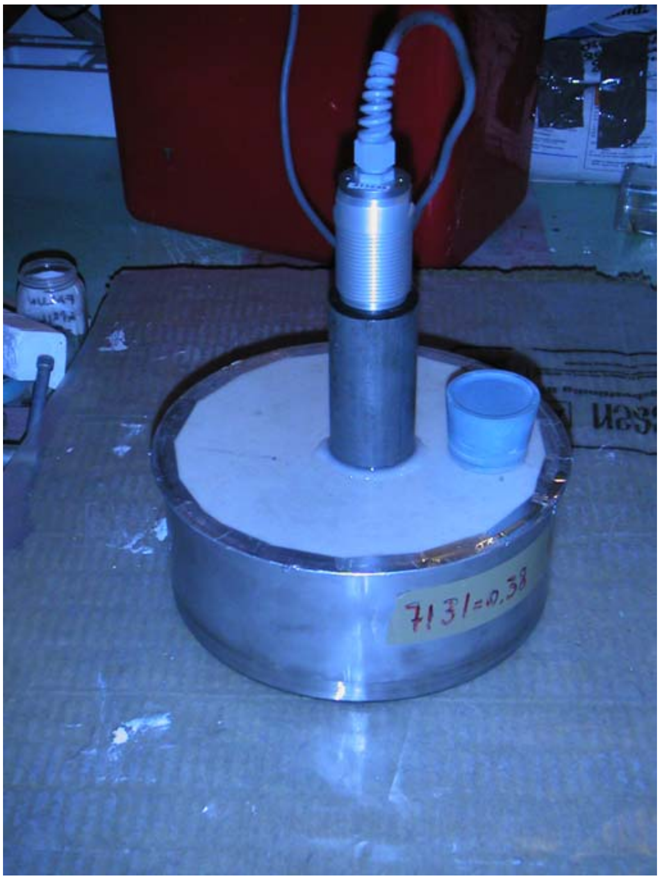

Figure 2. Set-up for measuring the relative humidity under the flooring.

3 Results

The results of the emission tests are given in tables A, B and C in the Annex. The results of the moisture measurements are given in tables D, E and F and the weight losses are given in tables G, H and J in the Annex.

3.1 Moisture

The results from the moisture measurements show that in investigation A, the different drying times have resulted in the desired different relative humidity under the flooring half a year after the application of the flooring. The values measured at this time – 86, 91 and 96% RH – have been used in the further presentation of the results, and also in Table A of the Annex.

In investigation B, the aim was to get a high relative humidity, by using a short drying time, and this aim was achieved as the measured RH was 95% after half a year. Bearing in mind that the uncertainty of the RH measurement is estimated at ± 2 % RH, the humidity in investigation B is not significantly different from the highest level in investigation A.

The RH measurements on the emission specimens in investigation A and B which were done after the finished emission measurements show a slight decrease, indicating that the floorings have had a high resistance to water vapour diffusion. This is also seen in the weight loss measurements. One exception is the sample with only concrete and the highest humidity in investigation A. It had decreased from 96% RH to 86% RH after 4.5 years, contrary to the samples with levelling compounds.

In investigation C, the different water/binder ratios of the concrete have resulted in different RH after half a year, as was expected. The measurements after the finished emission tests show a further decrease in RH, contrary to investigation A and B, which indicates that the self-desiccating of the concrete goes on. The results from the measurements at SP coincide fairly well with the measurements in Djursholm. SP states that the accuracy of their measurements is ± 5 % RH, because they have a suspicion that chemical contaminations may influence the result.

3.2 Application directly on concrete

In all three investigations, floorings were applied directly to concrete. An analysis of the results shows that the emissions vary widely. In Figure 3, the results from the reference concretes are shown. B1 and B2 are twin specimens from investigation B and C1 and C2 are twin specimens from investigation C. The relative humidity of 85%, as indicated in the figure, is based on earlier experience from the reference system. It was unfortunately not measured half a year after the application of the flooring, but only after 2.6 - 3 years. Then the humidity was 81 – 84% RH, as shown in Table F of the Annex. Ideally, these four samples should have identical values, but obviously they do not. It is rather certain that the differing results are not caused by errors in the emission measurements – then one would have had a much more inconsistent picture for the measurements done at different times.

The predominant emission in Figure 3 is 1-butanol, which is a result of alkaline hydrolysis of the butyl acrylate in the adhesive. Since the butanol emission is decreasing, the TVOC is also decreasing with time. The 2-ethylhexanol, on the other hand, increases with time. It most probably comes from decomposition of the phthalate plasticiser in the PVC according to the mechanism described in (16). There is no source for 2-ethylhexanol in the reference adhesive. The difference for 2-ethylhexanol between the four samples is not at all as big as for the 1-butanol.

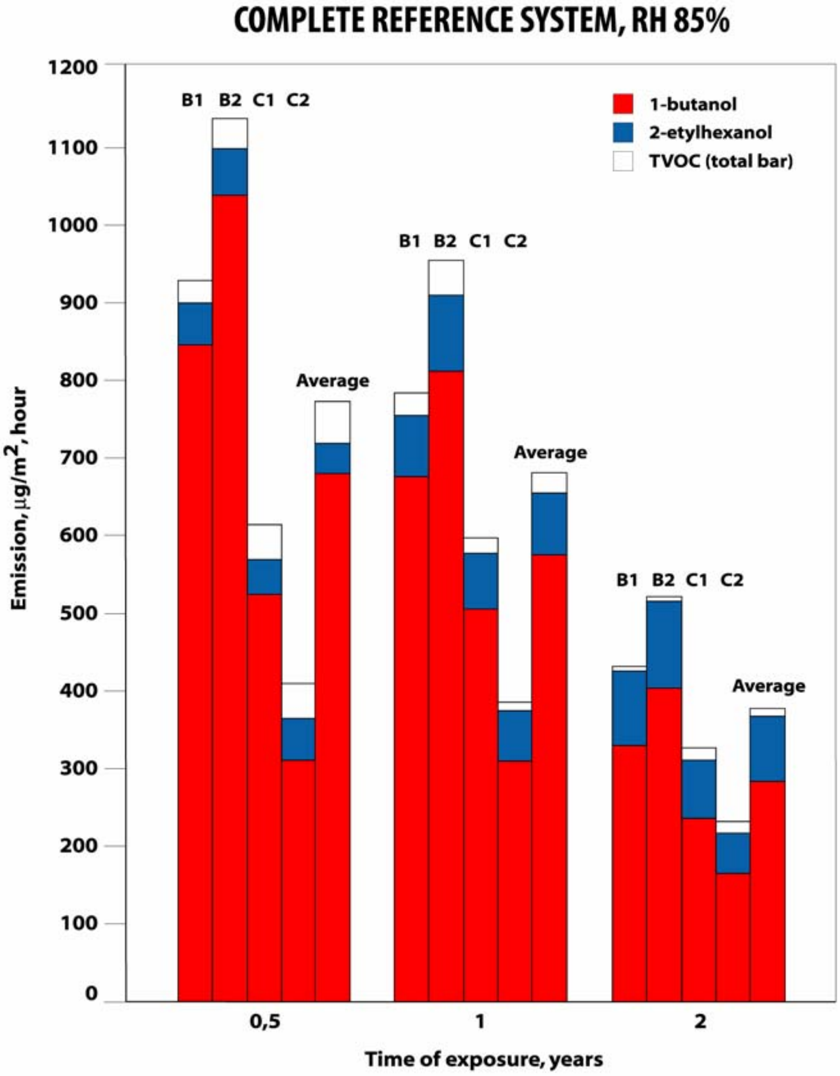

Figure 3. Emissions from complete reference system according to (9). B1, B2, C1 and C2 are individual samples from investigations B and C. Data are found in the Annex.

One can only speculate why there are such big differences between the samples. The most probable explanation is that even small differences in the properties of the concrete surface, can be of great importance for the aggressiveness. The high cement content of the reference concrete probably contributes to strengthen such differences. Similar big differences have been found in a project run by the Swedish Flooring Federation (17).

Considering the great differences for the reference concretes, it is not surprising that also the other concretes used in the investigations, show greatly differing emissions. The highest emissions were found with the concrete with the water-binder ratio of 0,7 and a relative humidity of 96 %. The lowest emissions were found for the self-desiccating concretes. But all concretes showed some emissions from degradation of adhesive and flooring. Therefore maybe it is not so important to try to analyse in detail under which conditions you get more or less emissions when applying the flooring directly on concrete. It is rather more interesting to see under which circumstances the degradation can be hindered by the use of low alkali levelling compounds. This will be dealt with in the following paragraphs. At the same time, some further aspects on the emissions from flooring applied directly on concrete will be given.

3.3 Influence of levelling compounds

From earlier investigations, (1-13), it has been found that levelling compounds based on calcium aluminate cement have a beneficial influence with respect to secondary emissions from adhesives and floorings. The reason for this effect is most likely primarily due to the fact that calcium aluminate cement is much less alkaline than ordinary Portland cement.

The purpose of the investigations presented here was to study the influence of levelling compounds in more detail. In investigation A, the aim was to find out if there is an upper limit for the relative humidity, over which the barrier effect of the levelling compound is lost. In investigation B, the influence of the binder system and the thickness of the levelling compound was studied at high humidity. And in investigation C, the combination of levelling compounds and self-desiccating concrete was examined.

3.3.1 Influence of relative humidity

In Figure 4-6, the results from ABS 148 are presented and compared to the case when the flooring is adhered directly to concrete. The indicated relative humidity is that which was measured half a year after the application of the flooring. The results are striking.

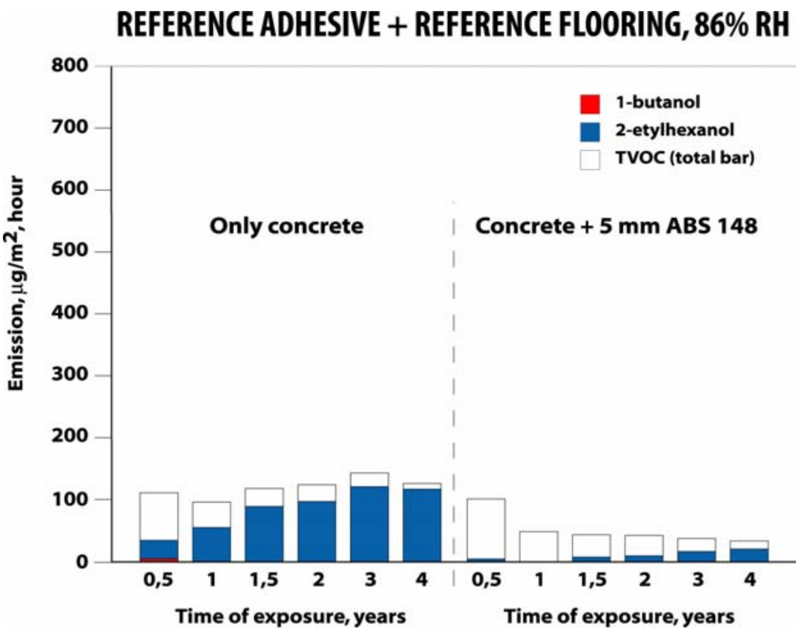

Figure 4. Emissions from composite structures on concrete with water/binder ratio = 0.7 and 86% RH (measured half a year after the application of the flooring)

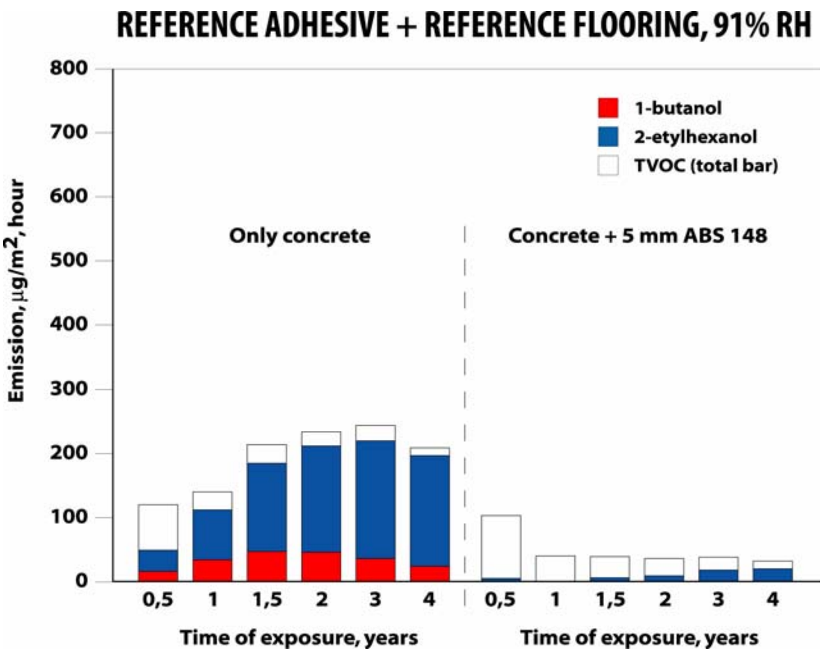

Figure 5. Emissions from composite structures on concrete with water/binder ratio = 0.7 and 91% RH (measured half a year after the application of the flooring)

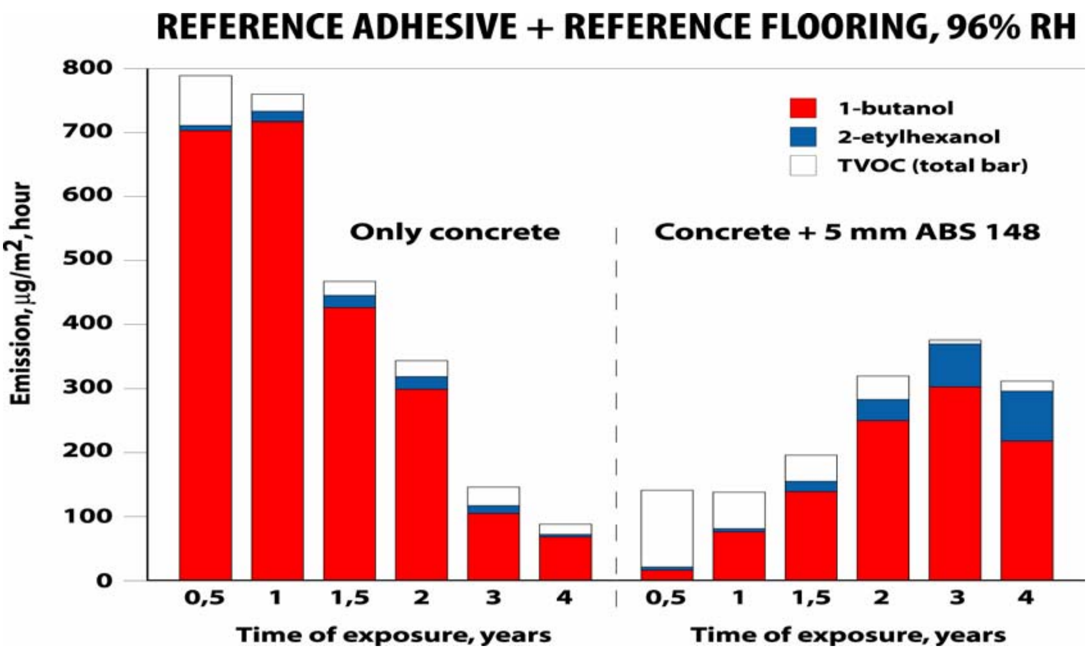

Figure 6. Emissions from composite structures on concrete with water/binder ratio = 0.7 and 96% RH (measured half a year after the application of the flooring)

For concrete, the emissions of alcohols increase considerably when the relative humidity increases from 86% to 96%. It is not only the extent of emission that is influenced by the humidity - also the character changes. At the highest humidity, 96%, the 1-butanol emission is quite dominating and it decreases sharply after the first year of exposure. At the medium humidity, 91 %, there is still some 1-butanol but the 2-ethylhexanol emission is higher and it increases up to three years of exposure, when it slowly starts to decline. At the lowest humidity, 86%, there is hardly any 1-butanol, but an appreciable emission of 2-ethylhexanol, again increasing up to three years and then slowly declining.

The reason for these rather dramatic differences in emission behaviour is not obvious, The 1-butanol is thought to emanate from alkali hydrolysis of the butyl acrylate in the adhesive, while the probable source of 2-ethylhexanol is hydrolysis of the di-ethylhexylphthalate plasticiser (DOP) in the PVC. The 2-ethylhexanol is typically increasing with time - contrary to the 1-butanol. It most probably emanates from the DOP, since there is no source for it in the adhesive. The plasticiser probably migrates downwards to the substrate, where it is attacked by alkali.

It has been suggested, (13), that the 2-ethylhexanol should come from the adhesive, but at a slower rate than the 1-butanol. This can certainly be true for some adhesives (1, 9), but for the adhesive used here it is not consistent with the results at 86% RH, where there is no 1-butanol, but increasing amounts of 2-ethylhexanol with time.The strange result that there is more emission of 2-ethylhexanol at 91 and 86% RH, than at 96% RH, indicates that there is some kind of interaction between the reaction of the adhesive and the DOP.

At 86% and 91% RH, there is hardly any emissions of alcohols when the concrete is covered with 5 mm of ABS 148 levelling compound, as can be seen in Figures 4 and 5. So, in fact, the results show that 5 mm ABS 148 at 91 % RH has a better emission performance than concrete at 86% RH.

At 96% RH, after half a year of exposure, the emissions of alcohol from the specimens with ABS 148 are very low and it looks as if the levelling compound can act as a protection against alkali attack even at this high humidity. But as time goes by, the protection is lost and the alcohol emissions are increasing up to three years. The reason for this is probably that alkali from the concrete is transported through the levelling layer and reaches the adhesive after some time.

Since alkali only can be transported in a liquid phase, it needs continuous water channels to be able to reach the adhesive through the levelling compound. And such continuous water channels only appear if the humidity is high enough. The results show that 96% is above a critical value, while 91% is below, for this combination of concrete (water-binder ratio 0.7) and levelling compound ABS 148.

It is interesting to note that the weight loss through the flooring (see Tables G, H and J in the Annex), is generally lower for the samples with levelling compounds as compared to the pure concrete ones. This difference exists at the different levels of humidity. It may reflect that the alkali attack on the flooring affects the resistance against water vapour transport.

3.3.2 Influence of different levelling compounds

The question arises whether other levelling compounds could have different critical humidity for the transport of alkali. In investigation A, also Strå Universal was used besides ABS 148. The results are found in Table A in the Annex. They show very similar results at 86 and 91% RH for both levelling compounds, i.e. no emission of 1-butanol and very limited emission of 2-ethylhexanol. At 96% RH, both levelling compounds behave principally in the same way, i.e. increasing emissions over time, although Strå Universal has somewhat lower values than ABS 148. The conclusion from this is that the critical humidity for both products is practically the same – between 91 and 96% RH.

ABS 148 and Strå Universal are commercial products with proprietary formulations. One difference is that ABS 148 contains ordinary Portland cement (OPC) in combination with calcium aluminate cement (CAC), while Strå Universal has only CAC as cement binder. In order to investigate whether this difference in binder system had any importance with respect to emissions, investigation B was carried out. In this investigation, a new product under development, ABS 3100, was tested with two different formulations – with or without OPC in combination with CAC. In the formulation with OPC, the OPC was 35% of the total cement content. Otherwise, the formulations were identical. Two specimens with the full reference system were also done, the result of which have already been presented in Figure 3 above.

The investigation was performed at high humidity, 95% RH, with a conventional concrete (water-binder ratio 0.62). The reasons for selecting the high humidity was to provoke emissions in order to see any differences, as found in investigation A. Two different thickness were used, 2 and 5 mm. Investigation B was done both with reference adhesive + reference flooring and Cascoproff 3448 + Tarkett Eminent. The results from the investigation are displayed in Figures 7 and 8.

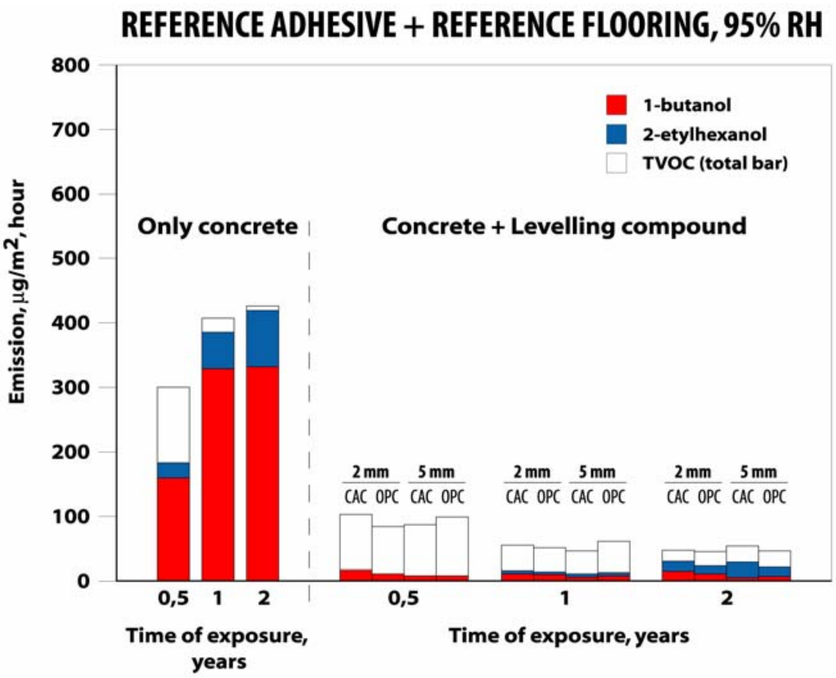

Figure 7. . Emissions from composite structures on concrete with water/binder ratio = 0.62 and 95% RH (measured half a year after the application of the flooring). Reference flooring system. Levelling compound CAC has only calcium aluminate cement, while levelling compound OPC has a combination of ordinary Portland cement and calcium aluminate cement.

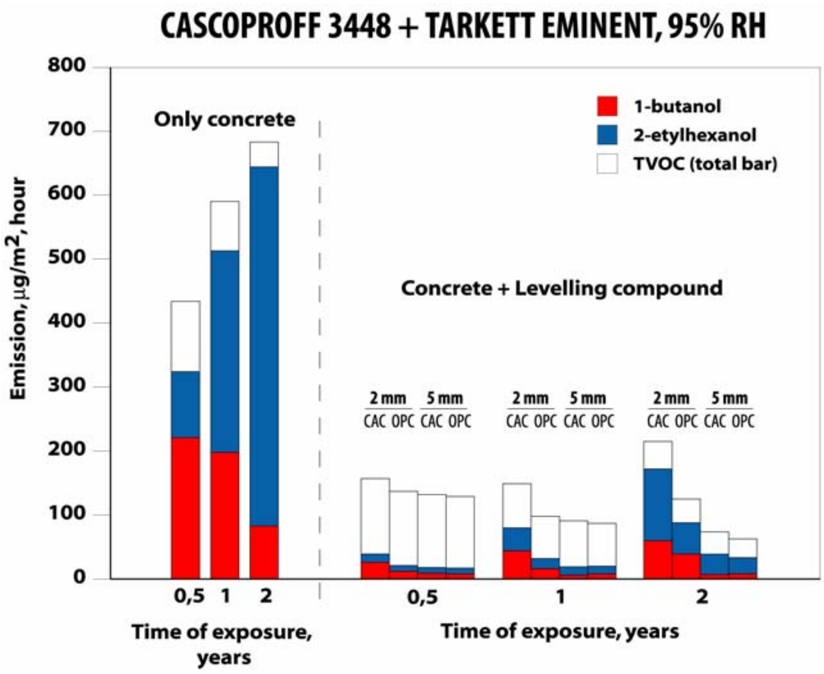

Figure 8. Emissions from composite structures on concrete with water/binder ratio = 0.62 and 95% RH (measured half a year after the application of the flooring). Commercial flooring system. Levelling compound CAC has only calcium aluminate cement, while levelling compound OPC has a combination of ordinary Portland cement and calcium aluminate cement.

Looking first at the specimens where the flooring was applied directly on concrete, one can see that the commercial system gives higher emissions at this humidity than the reference system – especially with regard to 2-ethylhexanol. This probably has to do with the fact that the commercial adhesive has acrylate components that can give emission of 2-ethylhexanol. Comparing back to Figure 3, which displayed the full reference system, i.e. also a reference concrete (water-binder ratio 0.5), it showed decreasing emissions with time, while Figure 7 has increasing emissions. This is probably due to the difference in humidity – the reference concrete gives about 85% RH. Comparing Figure 7 with Figure 5 and 6, a reasonable agreement is found, since Figure 7 with 95% RH has an appearance that is somewhere between the results at 91 and 96% RH. However, as mentioned before, there is no significance in the measured difference in humidity between 95 and 96% RH.

Looking at the results with the levelling compounds, the positive barrier effect is again demonstrated. In fact, for the reference adhesive and the reference flooring (Figure 7), the protection against alkali attack is indeed good even after 2 years, and no real difference is seen neither between the two different binder systems, nor between the compounds with different thickness. However, for the commercial flooring system, which gives higher emissions than the reference system, the levelling compound protection is functioning fairly well at 5 mm thickness but less well at 2 mm. The combined OPC-CAC system gives somewhat less emissions than the CAC-system, but principally they behave the same, i.e. increasing emissions with time at this humidity (95% RH).

So, even if there is some difference between different levelling compounds at very high humidity, both in investigation A and B, it is of minor importance since such high humidity should be avoided. The crucial conclusion is that the barrier effect of the tested levelling compounds functions up to a critical humidity, which seems to be between 91 and 95% RH. There seems to be a certain effect of the increase in thickness from 2 to 5 mm. For safety reasons, it is suggested that the maximum humidity should not exceed 90% RH and the thickness should not be less than 5 mm, in order for the tested compounds to give the desired protection against alkali attack from the underlying concrete on adhesives and flooring.

3.3.3 Emissions from concrete

In investigation B, a volatile organic compound appeared that we had not seen before, viz. 2-butanon, see the Annex. After half a year, the average over ten samples was 44 $\mu g/(m^2.hour)$, with somewhat higher values for the two concrete specimens, as compared with those with levelling compounds. After one year, the emissions of 2-butanon had decreased to 8 $\mu g/(m^2. hour)$ on the average and after two years it could no longer be detected.

Since 2-butanon did not appear for samples with reference concrete, it is reasonable to think that it emanates from the concrete used in this investigation. It was a commercial concrete from AB Betongindustri, using a superplasticiser called Glennium, and a qualified guess is that this maybe the source for 2-butanon. It is probably a primary emission that is somewhat hindered by the levelling compounds, and of course by the flooring. It is not considered to have anything to do with the subject of this report, i.e. alkali attack on adhesives and flooring.

3.3.4 Combinations of self-desiccating concrete and levelling compounds

Current recommendations from the Swedish Flooring Federation and adhesive producers state that PVC should not be adhered to concrete at higher humidity than 85% RH. Investigations A and B show that using the tested levelling compounds, the permissible humidity can be raised to 90% RH, and yet the emission behaviour is better than for concrete at 86% RH. This means a considerable shortening of drying times for concrete, but even so, the necessary drying time can be long, especially for thick structures.

A way of addressing the drying problem is the use of so-called self-desiccating concrete with a low water-binder ratio, which has a high degree of internal drying caused by the hydration of the cement. But earlier investigations have shown that adhering PVC directly to self-desiccating concrete has resulted in emissions of alcohols, in spite of low humidity (7,8). One possible reason for this may be that low water-binder ratio makes the concrete surface very dense, so that the water from the adhesive causes a locally very high relative humidity at the surface. Another reason could be that high cement content can increase the aggressiveness of the concrete.

In investigation C, the idea was to combine self-desiccating concrete with levelling compounds by taking advantage of the self-desiccating but eliminating the aggressive surface problem. The investigation was done with three different water-binder ratios of the concrete. The levelling compounds used were ABS 155 at 2 and 5 mm and ABS 148 at 5 mm. The majority of the tests were done with reference adhesive and reference flooring, but some specimens were also done with Cascoproff 3448 and Tarkett Eminent. Finally, two specimens with the full reference system were done, the result of which have already been presented in Figure 3 above.

The data from investigation C are shown in the Annex. The results with reference adhesive and reference flooring are displayed in Figure 9. The emissions after half a year from the floorings applied directly on concretes are of the same order of magnitude as in Figures 4 and 5, i.e. for concrete with water-binder ratio of 0.7 and 86-91% RH. But the long-term behaviour differs, as the emissions from the self-desiccating concretes are declining contrary to the concrete with higher water-binder ratio. This can be due to the fact that the humidity decreases with time in self-desiccating concrete (down to 70 – 75% RH, as shown in Table F of the Annex), which is not the case for the concrete with high water-binder ratio. The reason can also be that the effect of moisture in the adhesive declines with time.

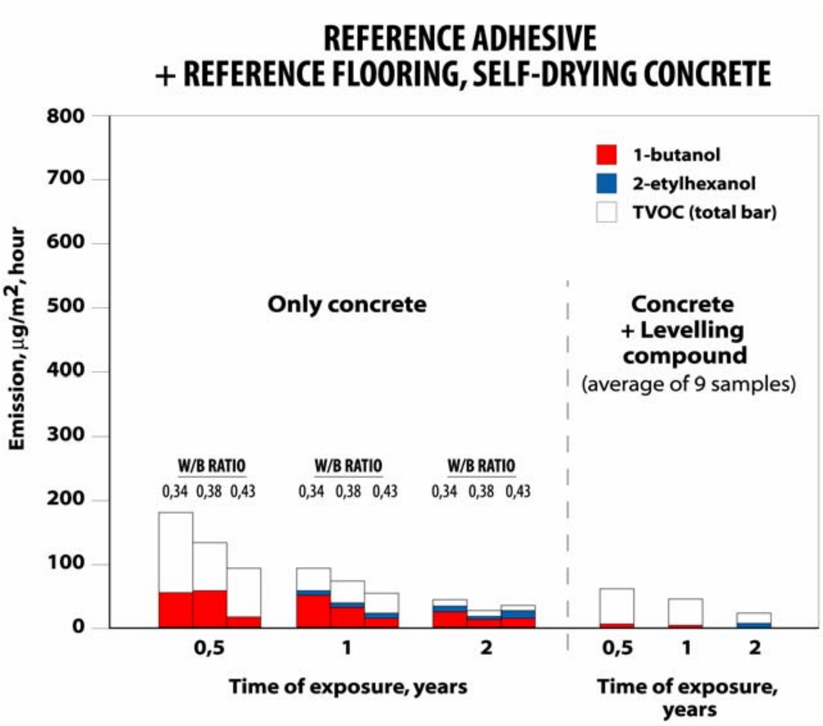

Figure 9. Emissions from composite constructions on self-desiccating concrete with different water/binder ratios. The results with levelling compound are the average of 9 samples.

The results with levelling compounds on self-desiccating concrete were very similar for ABS 155 and 148. Nor was there any obvious difference between 2 and 5 mm thickness for ABS 155. Therefore all nine samples with levelling compound with reference adhesive and reference flooring have been averaged in Figure 9. As can be seen, the emissions are very low. This was also the case when commercial flooring was used, as can be seen from the data in the Annex.

So, the idea to combine self-desiccating concrete and a low alkali levelling compound has been shown to protect against emissions from degraded adhesives and flooring, without extensive external drying. The water-binder ratio of the concrete does not have to be extremely low. In this investigation, 0.43 was low enough, in spite of the fact that the concrete was held under water for 28 days in order to simulate rain, before drying it for 14 days.

In investigation C, again some 2-butanon was detected as in investigation B. The same superplasticiser, Glennium, as in investigation B was used in the self-desiccating concretes. The emissions of 2-butanon are lower than in investigation B and they decline more rapidly.

4 Conclusions

The main conclusion from the investigations is that low alkali levelling compounds, based on calcium aluminate cement, can act as protection of adhesives and PVC floorings against alkali attack from aggressive concrete substrates. However, there is an important limitation – the humidity in the substrate must not be too high, otherwise the barrier effect can be lost because of alkali from the concrete being transported through the levelling layer after long-term exposure. The critical level seems too be between 91 and 95% RH, For safety reasons, it is recommended that the humidity should not exceed 90% RH.

The barrier effect of the levelling compound has been proved to exist even at such a small thickness as 2 mm, but again for safety reasons, a minimum of 5 mm is recommended.

The different levelling compounds used in the investigation showed principally the same behaviour with respect to protection against alkali attack, i.e. a good function below the critical humidity and a gradual loss of protection at higher humidity.

One way of restricting the humidity of the substrate without extensive drying times is to use self-desiccating concrete. When using self-desiccating concrete alone, adhesives and floorings are attacked in spite of low humidity, but using a combination of levelling compound and self-desiccating concrete, emissions from alkali attack can be avoided. Since the low humidity of the self-desiccating concrete is a built-in material property, which functions even if the concrete is soaked with water, humidity measurements on site can be reduced to a minimum if the water-binder ratio is low enough. In this investigation, a water-binder ratio of 0.43 proved satisfactory. The concrete producer should guarantee the self-desiccating properties of the concrete.

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ANNEX

The emission data for TVOC, 1-butanol, 2-ethylhexanol and 2-butanon from the three investigations are shown in the tables A-C below for the different exposure times. The emissions are given as toluene equivalents in μg/(m^2.hour).

Concrete qualities and drying conditions are shown in Table 1 of the report. Levelling compounds and their drying conditions are shown in Table 2.

Results of the moisture measurements are given in Tables D-F and weight losses through the flooring are shown in Tables G-J below.

Tables K and L describe the reference adhesive and the reference flooring.

Table A. Emissions results from investigation A, μg/(m^2·hour) in toluene equivalents.

Emission μg/(m^2.hour)	Exposure time,years	86% RH*			91% RH*			96% RH*		
		Concr	+148	+Univ	Concr	+148	+Univ	Concr	+148	+Univ
TVOC	0,5	112	102	86	120	103	79	789	141	115
	1	97	49	39	140	40	28	760	138	85
	1,5	119	44	34	214	39	30	467	196	123
	2	125	41	29	234	36	24	344	320	188
	3	144	38	28	244	38	28	146	376	226
	4	127	34	24	209	32	30	88	312	196
1-butanol	0,5	5	-	-	16	-	-	703	16	7
	1	-	-	-	34	-	-	717	76	35
	1,5	-	-	-	47	-	-	426	139	82
	2	-	-	-	46	-	-	299	250	129
	3	-	-	-	36	-	-	105	303	134
	4	-	-	-	24	-	-	63	218	102
2-ethylhexanol	0,5	30	5	5	33	5	14	8	5	5
	1	56	-	-	78	-	-	16	5	-
	1,5	90	8	6	138	6	-	19	16	14
	2	98	10	7	166	9	5	20	33	30
	3	122	17	11	184	18	10	12	67	62
	4	118	21	14	173	20	15	9	78	75

* The relative humidity is measured half a year after the application of the flooring.

Table B. Emission results from investigation B, $\mu g/(m^2 \cdot hour)$ in toluene equivalents

Adh+ Floor	Spec	TVOC			1-butanol			2-ethylhexanol			2-butanon		
		0,5 y	1 year	2year	0,5 y	1 year	2year	0,5 y	1 year	2year	0,5 y	1 year	2year
Ref + Ref	Only Concr	300	407	426	159	329	332	24	56	87	73	16	-
	+2mm CAC	103	55	47	12	11	15	-	5	15	55	8	-
	+5mm CAC	87	46	50	8	6	<5	-	5	24	34	5	-
	+2mm OPC	84	52	45	11	10	11	-	<5	12	24	-	-
	+5mm OPC	99	61	46	8	8	7	-	<5	14	52	8	-
Casco Proff + Tarke Emine	Only Concr	434	590	683	221	198	83	103	315	561	57	14	-
	+2mm CAC	157	149	215	26	44	60	13	36	112	41	10	-
	+5mm CAC	132	91	79	9	6	7	9	13	32	29	5	-
	+2mm OPC	137	98	125	12	16	39	9	16	49	39	8	-
	+5mm OPC	129	87	65	8	8	8	9	12	22	40	10	-
Ref + Ref	Ref concr	931	786	434	848	678	332	54	79	96	-	-	-
		1140	957	524	1041	814	406	60	98	112	-	-	-

Table C. Emission results from investigation C, $\mu g/(m^2 \cdot hour)$ in toluene equivalents

Adh+ Floor	Spec	TVOC			1-butanol			2-ethylhexanol			2-butanon		
		0,5 y	1 year	2year	0,5 y	1 year	2year	0,5 y	1 year	2year	0,5 y	1 year	2year
Ref + Ref	**W/B 0,34**	179	92	43	54	50	24	-	7	9	29	-	-
	+2mm 155	63	44	21	8	7	6	-	-	6	5	-	-
	+5mm 155	46	44	21	7	5	<5	-	-	6	-	-	-
	+5mm 148	52	36	23	5	-	<5	-	5	9	-	-	-
	W/B 0,38	132	72	26	57	31	12	-	7	5	33	-	-
	+2mm 155	62	44	29	7	6	<5	-	-	<5	16	-	-
	+5mm 155	52	46	23	7	5	<5	-	-	6	-	-	-
	+5mm 148	40	35	25	-	-	<5	-	-	9	-	-	-
	W/B 0,43	92	53	34	16	14	14	-	8	12	34	5	-
	+2mm 155	78	50	19	7	6	<5	-	-	<5	30	-	-
	+5mm 155	69	52	20	6	5	<5	-	-	6	16	-	-
	+5mm 148	90	56	23	7	5	<5	-	-	8	36	6	-
Casco Proff + Tarke Emine	**W/B 0,43**	125	116	57	-	-	<5	5	9	10	24	5	-
	+5mm 148	122	105	56	-	-	<5	5	9	11	19	-	-
Ref + Ref	**Ref concr**	616	599	329	527	508	238	45	72	75	-	-	-
		412	388	234	313	312	167	54	65	52	-	-	-

Table D. Relative humidity in investigation A.

Second drying , Days	Specimen	RH after 0,5 year, %	RH after 4,5 years, %
1	Concrete	96	86
	Concrete + 148		95
	Concrete + Universal		93
14	Concrete	91	87
	Concrete + 148		87
	Concrete + Universal		87
28	Concrete	86	85
	Concrete + 148		85
	Concrete + Universal		85

Table E. Relative humidity in investigation B.

Adhesive + flooring	**Specimen**	**RH after 0,5 year, %**	**RH after 2,5 years, %**
Reference adhesive + Reference flooring	Only Concrete	95	93
	+ 2mm CAC		93
	+5 mm CAC		93
	+2 mm OPC		94
	+5 mm OPC		93
Cascoproff 3448 + Tarkett Eminent	Only Concrete	95	94
	+ 2mm CAC		93
	+5 mm CAC		92
	+2 mm OPC		92
	+5 mm OPC		92

Table F. Relative humidity in investigation C.

Adhesive + flooring	Specimen	RH after 0,5 year, %	RH at SP after 2,6 years,%	RH after 3 years, %
Reference adhesive + Reference flooring	W/B 0,34	81	71	69
	+2mm155			70
	+5mm155		73	72
	+5mm148			71
	W/B 0,38	85	75	75
	+2mm155			78
	+5mm155		75	78
	+5mm148			77
	W/B 0,43	88	75	77
	+2mm155			76
	+5mm155		84	81
	+5mm148			82
Cascoproff 3448 + Tarkett Eminent	W/B 0,43		82	82
	+5mm148		81	82
Ref +Ref	Ref concrete		84	81
			82	83

Table G. Weight losses through flooring in investigation A

Second drying , Days	Specimen	Weight loss, $g/(day \cdot m^2)$		
		2,6 – 2-8 years	2,8 – 3 years	3 – 4 years
1	Concrete		2,19	1,77
	Concrete + 148	0,58	0,76	0,61
	Concrete + Universal	0,78	1,27	0,94
14	Concrete	1,19	1,65	1,39
	Concrete + 148	0,90	1,17	1,02
	Concrete + Universal	0,81	1,11	0,96
28	Concrete	0,72	0,98	0,90
	Concrete + 148	0,43	0,51	0,45
	Concrete + Universal	0,49	0,67	0,58

Table H. Weight losses through flooring in investigation B

Adhesive + flooring	Specimen	Weight loss, g/(day·m^2)		
		0 –0,5 year	0,5 – 1 year	1 – 2 years
Ref +ref	Only Concrete	2,53	2,27	2,15
	+ 2mm CAC	1,66	1,38	1,02
	+5 mm CAC	1,82	1,19	1,15
	+2 mm OPC	1,49	1,08	1,06
	+5 mm OPC	1,47	0,98	0,96
Cascoproff+Eminent	Only Concrete	2,13	1,52	1,52
	+ 2mm CAC	1,34	0,95	0,98
	+5 mm CAC	1,30	0,89	0,96
	+2 mm OPC	1,10	0,79	0,77
	+5 mm OPC	1,43	1,10	1,15

Table J. Weight losses through flooring in investigation C

Adhesive + flooring	Specimen	Weight loss, g/(day·m^2) 1 –2 years
Reference adhesive + Reference flooring	W/B 0,34	0,79
	+2mm155	0,35
	+5mm155	0,56
	+5mm148	0,64
	W/B 0,38	1,00
	+2mm155	0,48
	+5mm155	0,61
	+5mm148	0,65
	W/B 0,43	1,00
	+2mm155	0,50
	+5mm155	0,53
	+5mm148	0,39
Cascoproff 3448+ Tarkett Eminent	W/B 0,43 +5mm148	0,46
		0,68

Table K. Description of the reference adhesive

Contents	%
Water	30,0
Hydroxyethyl cellulose	0,4
Butylakrylat polymer	30,0
Sodium polyacrylate	0,5
Paraffin mineral oil	0,1
Conservatives ♦ 2-brom-2-nitro-1,3-propanol ♦ methyl-klor-isotiazolinon ♦ methyl-isotiazolinon	0,1
Calcium-magnesium carbonate	30,4
Triethylene glykolester from pine resin	8,5
TOTAL	100,0

Table L. Description of the reference flooring

Contents	%
S-PVC	48
Di-ethylhexylphthalat	20
CaZn-stabilizator	1
Epoxidated soybeanoil	1
Calciumcarbonate (filler)	30
Total	100