DURABILITY OF ROOF UNDERLAYS EXPOSED TO LONG TIME EXPOSURE UNDER IN-USE CONDITIONS

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ABSTRACT
In Denmark water tightness of roof underlays is of great importance as the underlay serves as the final barrier against water ingress in roof constructions. A popular trend is pitched roofs with ceilings parallel to the roof surface leaving no or very poor accessibility for inspection and repair of the roof underlay.

Roof underlays used in Denmark are to a large extent based on flexible polymer sheets or fibre boards with a coating on the upper side. The underlays are not supported by a rigid underlay.

The durability of the roof underlay is crucial in order to maintain the water tightness for the entire service life of the roof covering. Especially taking into consideration that there is a frequent use of clay tiles and similar where wind-driven rain has fairly easy access to the roof underlay. Also, some clay tiles allow a relatively high amount of solar radiation to pass through the corner joints thereby allowing degradation due to UV light.

The paper presents results from testing of water tightness of different types of roof underlays including a wood fibre board and a gypsum board. Results are mainly from test specimens of nine different roof underlays which were exposed to in-use conditions in a test house at the Danish Building Research Institute. Specimens at the test house were exposed to the south and to the north respectively. These specimens have been exposed for about 18 years. The results from the test house are supplemented by results from a small number of test specimens taken out from buildings after some years of service.

The results of the investigations are that a major part of roof underlays commercially available in the 1990ies degrade considerably in-use thereby losing its water tightness.

1 INTRODUCTION
For quite some years it has in Denmark been common practice to use roof underlays (also designated sarking felt or underlayment) for sloping roofs with roof coverings of tiles or slates.

The purpose of the roof underlay is primarily to act as a barrier against water penetrating through the roof covering itself. In Denmark some types of roof coverings – especially clay pantiles with small overlapping joints, and fibre cement slates – are fairly open to water especially in the form of wind-driven rain. Further, some clay pantiles allow a relatively high amount of solar radiation to pass through the corner joints. All tile or slate roof coverings will allow drifting snow to pass unless special solutions e.g. mechanically tightened joints are used.

Roof underlays are also used for metal roof coverings in order to catch drips from condensation on the backside of the roof covering.

The roof underlay must not jeopardize the natural moisture transportation by diffusion through the roof construction. Traditionally this has been achieved by using roof constructions
with a ventilation gap between the insulation and the roof underlay. In such cases vapour tight materials perform very well as long as the ventilation space has sufficiently large openings to the surroundings.

About 20 years ago a new type of materials was introduced to the market as alternatives to the existing roof tile underlays - not only were they watertight but they were also vapour permeable. A relatively large part of these materials is based on flexible polymer sheets fastened to the trusses, i.e. not supported by a rigid underlay but also wood fibre boards and gypsum boards were used as roof underlays.

These new roof underlays - which are very open to water vapour diffusion - are used in a different way than previously as they are placed directly on the insulation without the traditional ventilation gap between insulation and roof tile underlay. As the ventilation gap is omitted such roof constructions can be made thinner but consequently do not have the possibility of removing moisture by ventilation. Moisture penetrating from the interior of the building must consequently be removed by diffusion through the roof underlay instead of by ventilation under the roof underlay. The materials used for the roof underlay must be water vapour permeable to such an extent that moisture is not accumulated inside the construction.

A popular trend in contemporary Danish architecture is pitched roofs with ceilings parallel to the roof surface leaving no or very poor accessibility for inspection of the roof underlay. For use in such constructions roof underlays with long service lives are required – if possible the service life should be the same as for the roof covering.

In earlier studies, [1] and [2], the most important properties for roof underlays were found to be:

- **Tightness against precipitation** – this property is especially required during the construction period until the primary roof has been laid.
- **Tightness against water** – this property covers standing water as well as water running on the surface. When well-constructed no ponding should occur on the roof underlay.
- **No tent effect** – tent effect refers to the well-known fact that touching of the inside of a tent during rain may cause penetration of water. For underlayment laid directly on wood and insulation, no tent effect should occur, as it would impair the water tightness.
- **Water vapour permeability** – for unvented constructions it is evident that moisture from the interior of the building can only escape through the underlayment by diffusion. Consequently the material shall be very permeable to diffusion of water vapour.
- **Moisture accumulating properties** – are a supplementary asset if all other requirements to the roof are fulfilled. It allows the up-take and accumulation of moisture during periods with high exposure. The moisture is allowed to be removed during other periods.

### 2 RESULTS FROM TEST HOUSE

To investigate the behaviour of unventilated roofs a new roof construction was made on the test house at the Danish Building Research Institute (SBI) in 1995. The roof has a slope of $40^\circ$ (1:1.2) and consists of 11 pairs of elements, each pair with an element oriented towards north and south respectively.
Each element is 1 m wide and has a height of 240 mm. 10 pairs are unventilated and the last one - acting as a reference - is ventilated. The elements are made with two timber members as sides and with a gypsum board as interior surface. There is no vapour barrier but the gypsum board is painted to achieve a desired water vapour permeability. The elements are totally filled with mineral wool as thermal insulation. On the outside the roof underlay is placed directly on top of the insulation material. The roof underlay is fastened to the rafters and a counterbatten of 22 mm is attached to the rafters over the underlayment. The roof is finished with battens and roof tiles.

The climate in the test house is controlled in winter time to 23 °C (73 °F) and 60 % RH, i.e. a very high humidity level compared to the expected 30 % RH or less under winter conditions. The 60 % RH is chosen to make the exposure as harsh as possible simulating the worst possible in-door conditions. The performance of the tested roof underlays as regards their ability to let moisture from the interior of the building pass has been reported earlier [1] and [2]. The results show that membranes with a high permeability to water vapour can function as a roof underlay, i.e. the amount of water penetrating from the interior is removed by diffusion without causing accumulation of humidity in the construction.

For the present investigation 9 of the roof underlays have been removed from the test house and have been tested as regards tent effect and water tightness (under a head of water). Only the ventilated roof tile underlay and an underlay of plywood with a liquid applied moisture barrier were not tested. The nine roof underlays were tested separately for the specimens facing south and north respectively.

The specimens taken out were very dirty and all looked deteriorated to some degree. Examples are shown in figure 1. The specimens had clear marks of the battens. For one set of specimens small parts of the protecting membrane had fallen off, see figure 2. The wood fibre board and the gypsum board had no stains or discolourations from water on the back.
2.1 Testing of tent effect

Testing of tent effect comprises normally an accelerated ageing followed by a test of water tightness of the product when placed in contact with the substrate. For this investigation no accelerated ageing was performed as the intention was to find out how the roof tile underlays were deteriorated under in service conditions.

During the test of water tightness a flat aluminium "tray" is used to collect any water penetrating the underlayment during the water exposure, see figure 3. In the lower end of the tray a piece of mineral wool and in the upper end a piece of plywood is placed. Both materials are slightly higher than the aluminium tray. The underlayment is mounted on a wooden frame which fits around the aluminium tray. When mounted the frame is placed around the tray causing the underlayment to rest around the mineral wool and the plywood respectively. The underlayment is held in place by the weight of the frame and the underlayment themselves.

This situation is intended to simulate the conditions in a real roof. Water is sprayed from a nozzle over the entire surface of the specimen for 6 hours. The water pressure in front of the nozzle is very low simulating a fine to medium rain. The test method was in the late 1990ies elaborated into a Nordtest test method, NT BUILD 488, "Roof tile underlays: Water tightness - Tent effect" (may be downloaded from www.nordicinnovation.org). The result
using this test method is now part of the necessary documentation needed to obtain an “approval” of roof tile underlays in Denmark. The requirement used is that a maximum of 15g of water must pass during the 6 hours exposure to water.

![Figure 3: Testing of tent effect. The roof underlay is placed over a substrate partly of plywood partly of insulation material. Any water passing through the underlayment during exposure to water spray from the nozzle is accumulated in the aluminium tray and weighed.](image)

Table 1. Results of the testing of tent effect expressed as grams penetrated through the roof underlay after 6 hours water spray. The requirement normally used in Denmark is that a maximum of 15g of water must pass during the exposure to water

<table>
<thead>
<tr>
<th>Material no.</th>
<th>Type of roof underlay</th>
<th>North facing</th>
<th>South facing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flexible sheet</td>
<td>762</td>
<td>685</td>
</tr>
<tr>
<td>2</td>
<td>Flexible sheet</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
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</tr>
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<td>Flexible sheet</td>
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<td>181</td>
</tr>
<tr>
<td>5</td>
<td>Flexible sheet</td>
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<td>2080</td>
</tr>
<tr>
<td>6</td>
<td>Flexible sheet</td>
<td>120</td>
<td>171</td>
</tr>
<tr>
<td>7</td>
<td>Flexible sheet</td>
<td>841</td>
<td>1821</td>
</tr>
<tr>
<td>8</td>
<td>Wood fibre board</td>
<td>128</td>
<td>264</td>
</tr>
<tr>
<td>9</td>
<td>Gypsum board</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

2.1.1 Test material

The materials used for the testing were 7 different types of flexible sheets, 1 wood fibre board (oil impregnated) and 1 gypsum board (with surface impregnation). The materials were
all intended for use as unventilated roof underlays and commercially available on the time they were mounted in the test house.

Only one specimen of each type was available for the test because the test specimens are rather large. The results of the tests are shown in table 1.

Only one of the flexible sheets passed the test. The wood fibre board becomes moist during the test and water penetrates. The gypsum boards failed, as the carton on the upper side had deteriorated before the test and further lost adhesion to the gypsum core during the initial period of testing.

3 TENT TESTING OF SAMPLES TAKEN OUT FROM EXISTING BUILDINGS

For some years samples taken out from existing buildings have been tested, typically because problems were experienced with the roof underlay. A project was started together with a manufacturer to investigate the problem in a more systematic way. Unfortunately only one sample was taken out before the manufacturer decided to stop the project.

More than 20 roof underlays taken out from existing buildings have been tested and only one passed the test. This shows that there is a problem with lack of water tightness either because the products used have never been watertight or because they have deteriorated under service conditions. Many of the products tested have very poor performance as regards tent effect and are unlikely to provide protection against penetration of water.

The one product that passed the test was taken out from a leaking roof. In that particular roof the insulation layer in the roof was thicker than the nominal value (but still within the tolerances for thickness of the insulation). This results in a deformation of the roof underlay so the water cannot run off freely underneath the battens, see figure 4. Instead the water follow the slope of the roof underlay towards the trusses which means that water on the roof is accumulated at the counterbatten where it can penetrate through the holes from the nails. This means that focus not only should be on the material itself but also on the design and workmanship.

![Figure 4: Due to insulation material thicker than the trusses the roof underlay is pressed up against the battens in the middle. The water cannot run off freely and instead follow the slope of the roof underlay towards the trusses where it accumulates and results in water penetration at the nails.](image)

4 TESTING OF WATER TIGHTNESS

As a supplement to the testing of tent effect the specimens from the test house were also tested for water tightness under a head of water, in the same way as used in previous studies [3].

Tests of water tightness were performed in a plexiglass/acrylic glass cylinder with a 200 mm head of water. A filter paper was placed under the tested material to simulate tent-effect.
Water tightness between test material and container is obtained by a rubber sealing supplemented with silicone grease. The container is pressed against the lower plate with bolts in the four corners, see figure 5. The weight of the filter paper was determined before and after 60 minutes of testing. The tests were considered failed if the water uptake exceeded 0.5 g. The results of the test are shown in table 2.

![Diagram of test set-up for water tightness.](image)

**Figure 5:** Test set-up for water tightness. The test material is placed on the lower plexiglass/acrylic glass plate. Water tightness against the specimen is secured with a rubber seal and the container being pressed against the lower plate with bolts in the four corners. Water is poured into the cylinder until a water level of 200 mm above the test material.

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Material</th>
<th>Failed/tested</th>
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<tbody>
<tr>
<td>1</td>
<td>Flexible sheet</td>
<td>3/3</td>
</tr>
<tr>
<td>2</td>
<td>Flexible sheet</td>
<td>0/3</td>
</tr>
<tr>
<td>3</td>
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</tr>
<tr>
<td>4</td>
<td>Flexible sheet</td>
<td>3/3</td>
</tr>
<tr>
<td>5</td>
<td>Flexible sheet</td>
<td>3/3</td>
</tr>
<tr>
<td>6</td>
<td>Flexible sheet</td>
<td>3/3</td>
</tr>
<tr>
<td>7</td>
<td>Flexible sheet</td>
<td>3/3</td>
</tr>
<tr>
<td>8</td>
<td>Wood fibre board</td>
<td>3/3</td>
</tr>
<tr>
<td>9</td>
<td>Gypsum board</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2. Results of test of water tightness. The ratio between the number of failed and tested specimens after exposure to 200 mm head of water for one hour. The gypsum board was not tested as the carton was deteriorated and partly without adhesion to the gypsum core.

The results of these tests are similar to the testing of tent effect, i.e. a very large rate of materials failed.

A small investigation of the wood fibre board showed, that a pond of water (roughly 1 mm thick) placed on the surface was absorbed in the fibre board within a few minutes. Only after repeating the ponding four times small stains appeared on the back, i.e. the fibre board is able to absorb a fair amount of water before penetration to the back.
5 DISCUSSION

A prerequisite for the introduction of new materials without in-use experience is that the performance properties are documented and that the properties fit with the performance requirements for the use including the ability to withstand the exposure to the expected environment. Ideally such information should be given by the manufacturer but unfortunately information is often not available as was the case for the products tested in this investigation.

The results from the tests where 8 out of 9 materials fail after only 18 years of service are very disappointing and could mean increasing problems with leaking roofs in the years to come. These results are in accordance with the findings in a study carried out by Atelier Dek [3] where also big problems with service life were revealed. The need for better methods of accelerated ageing has also been discussed within CEN/TC 254 WG 9/10 [4], apparently because there is agreement about the need for better methods. Fortunately many of the products marketed in the 1990ies are no longer on the market and hopefully the new products have better performance than the tested ones.

The roof underlays of oil impregnated wood fibre boards and surface impregnated gypsum boards are no longer on the market. However, it is interesting to notice that neither of these had stains or discolourations on the back. This is possibly due to relatively small amounts of water penetrating through the roof covering itself and the fact that both are able to absorb rather large amounts of water.

The present results are in accordance with earlier findings [3] where it was concluded that the methods used for long term ageing of roof underlays are not sufficient to predict the service life of roof underlays. At least not with the type of roofing materials used in Denmark.

From building surveys and damage investigations a number of problems have been encountered apart from the problems with the materials themselves. The major problems seen so far are: 1) Mould growth on the back of the roof underlay due to vapour barriers that are not sufficiently airtight in order to avoid convection of moist indoor air to the roof construction. 2) Insulation layers pressing the roof underlay against the batten – as described earlier in this paper. 3) Insufficient designed details which allow penetration of water.

It is proposed that manufacturers should not only give guidance on what the products can be used for but should also provide well documented information on the expected service life of the product under the intended use. Besides manufacturers and/or suppliers should provide guidance for installation including information on all necessary details.

The building research bodies should help in making accelerated test methods simulating the in-use exposure in order to give reliable prediction of service lives.

REFERENCES