

Service Life (Model) for Bituminous Roofing

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ABSTRACT

Leaking low-sloped roofs, i.e., roofs with roofing felt or roofing membranes, have been responsible for extensive major damage to buildings all over the world. The causes have been several, e.g., bad materials – or rather materials and materials combination used in a way they were not suited for - bad design with difficult details hard to make at a building site and bad workmanship. In Denmark the problems have been dealt with in different ways including requirements for minimum slope, for the substrate and for the roofing felt/membrane. To avoid problems a model for service life prediction of low-sloped roofs was developed some years ago. The model was based on experience. The paper explains the background for the model and discusses how the model fits also with later gained experience. In addition, the paper describes an investigation on service life of SBS modified bituminous roofing carried out in cooperation between the Danish Bituminous Roofing Manufacturers, The Danish Roofing Advisory Board and the Danish Building Research Institute. The findings confirm the predictions of the model as regards SBS modified roofing felt.

KEYWORDS

Roofing material, Roofing felt, Low-sloped roofs, Service life, Modelling.

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1 INTRODUCTION

Leaking low-sloped roofs, i.e., roofs with roofing felt or roofing membranes, have been responsible for extensive major damage not only to the roof covering itself, but also to the underlying parts including underlay, trusses and occasionally to furniture and fixtures. In Denmark the causes for the problems have been several.

Earlier the use of horizontal roofs was quite common, as it gave an architectural impression which was popular at the time and besides alterations or expansion of the buildings was relatively simple. However the horizontal roofs led usually to ponding of water followed by destruction of the roofing felt/membrane due to formation of ice and prolonged exposure to humidity. Also the materials used earlier were less durable than materials used today, e.g., the glass fibre reinforcement in earlier generations of roofing felt led to brittle products and for PVC-roof membranes big problems were caused by shrinkage due to evaporation of plasticisers. Finally problems occurred due to the use of materials or combinations of materials used in a way they were not suited for, bad design with difficult details hard to make at a building site and bad workmanship.

In Denmark the problems have been dealt with in different ways. The horizontal roofs were abandoned when requirements for minimum slope were introduced in the building codes in 1981. New generations of materials have come to the market e.g., new reinforcement and plastic modified bitumen for the roofing felt and more suited plasticisers for PVC membranes. Also the underlay for the roofing is of importance for the service life of the entire constructions and here requirements have been set by the involved key partners, e.g., Danish Roofing Advisory Board.

2 SERVICE LIFE MODEL FOR ROOFS

It is not possible to state a precise service life for roofing materials because it is dependent on a number of different factors. Some years ago a model for service life prediction of low-sloped roofs was developed based on experience taking into account the factors considered most important for the deterioration of roof membranes in the past [Bunch-Nielsen, T., 1997]. The factors in the model are:

- The type of roof membrane (p - product)
- The number of plies (n)
- The slope of the roof (s)
- The substrate (u – underlay)
- The fastening to the substrate (f)
- The design, especially the details (d – design)
- The traffic on the roof (t – traffic)
- The maintenance (m)

Based on the factors the service life can be expressed as:

$$L = T \cdot p \cdot n \cdot s \cdot u \cdot f \cdot d \cdot t \cdot m$$

T is the anticipated service life for a reference roofing material. The remaining factors all have values between 0 and 1, i.e., T is the maximum service life on condition that all other factors are at their maximum.

2.1 Roof Membrane – The Product

In Denmark an important property for a roofing membrane is its ability to function in a cold climate with many freeze-thaw cycles. From assessments, we find that this is, on the average, best achieved with a SBS-modified bitumen. Consequently a roofing felt made from SBS-modified bitumen and reinforced with polyester carrier - which is the most commonly used roof membrane in Denmark – is

used as the reference in the model and the service life for a roof of this type is estimated to be 50 years, i.e., the factor T in the formula is 50 years. For other types of roof coverings a reduction factor is used according to the following:

Roof covering	SBS-modified bitumen	APP-modified bitumen	Oxidized bitumen	PVC reinforced	EPDM
Factor p	1.0	0.7-0.9	0.8	0.8	1.0

2.2 Number of Plies

The number of plies in a roof covering has bearing on the service life. In Denmark roof coverings are traditionally made with 2 plies (earlier in built-up roofs even more plies were used). The factors used are the following:

Number of plies	2	1
Factor n	1.0	0.8

2.3 Slope of The Roof

The slope of the roof is of importance for the time of wetness and for the risk of water ponds. Ponds on the roof may lead to a risk of a build-up of ice which can remove the protective granules or even tear the roofing material apart due to temperature movements under freeze-thaw cycles. The influence of the slope is expressed according to the following:

Slope	$\geq 1:5$	$\geq 1:20$	$\geq 1:40$	$< 1:40$
Factor s	1.0	0.9	0.8	0.6

2.4 The substrate – Roof Underlay

In Denmark a number of different substrates have been used and quite a few have been abandoned due to problems, e.g., lack of dimensional stability under in use conditions. Nowadays are used products with a record of satisfying performance under in use conditions, mainly boards such as plywood, oriented strand board (OSB), and insulation materials. In case "soft" insulation materials (compressive strength less than 40 kN/m²) are used it is necessary to apply a hard load distributing layer on top of the insulation. In addition, it is normal to renovate old roofs with roofing felt by applying a new layer on top of the old. The influence from the substrate is expressed as the following:

Substrate/underlay	"Soft" insulation	"Hard" insulation	Boards, Plywood, OSB	Old roofing On hard substrate	Other substrates without documentation
Factor u	0.7-0.9	0.9-1.0	1.0	1.0	0.6- 0.4

2.5 The Fastening to The Substrate

Fastening of a roof membrane to the substrate can be achieved in different ways. Traditionally roofing felt is bonded or torched to the substrate, but mechanical fastening has been the dominant method for the last 15 years. Membrane securement might also be achieved by ballasting the membrane. The influence from the fastening is expressed as the following:

Fastening	Bonded or welded roofing felt	Mechanically fastened 2 ply roofing felt	Mechanically fastened 1 ply roofing felt	Membrane fastened with ballast	Mechanically fastened synthetic membrane
Factor f	1.0	1.0	0.9	0.9	0.8

2.6 The Project – Design of Details

The design has a major influence on the service life and especially the design of the details. It is important to include here a requirement that the details shall be buildable, i.e., it shall be possible to construct the details on a building site. The risk for failures increases with the number of details on a roof and consequently the factors mentioned below should be reduced, e.g., by a factor 0.8 for roofs with many details. The factors used are the following:

Details	Details in accordance with TOR ¹ directions	Details not in accordance with TOR
Factor d	1.0	0.8

¹⁾ TOR is the Danish Roofing Roofing Advisory Board

2.7 Traffic on the Roof

The roofing material and the details can be damaged due to compression of the underlay from traffic on the roof. The influence of the traffic is expressed according to the following.

Traffic	Pedestrian traffic for maintenance of roof only	Pedestrian traffic for maintenance of mechanical installations, rooflights etc.	
		Hard substrate e.g., plywood	Soft substrate e.g., mineral wool
Factor t	1.0	0.8	0.6

2.8 Maintenance

The roof membrane itself is not anticipated to require maintenance, but details, e.g., flashings and joints and the drainage system need maintenance as part of preventive maintenance. The influence of the maintenance is expressed according to the following:

Maintenance	Maintenance according to TOR requirements	Maintenance not in accordance with TOR req.	No maintenance
Factor s	1.0	0.8	0.6 – 0.4

Because the assessments naturally are performed with a considerable uncertainty, the service life should only be given as the closest 5 year interval found as result of the calculation, e.g., 25-30 years.

3 SURVEY OF ROOFS WITH ROOFING FELT

To verify some of the assumptions in the service life model, 12 roofs have been surveyed. The roofs were all with bituminous roofing produced by Danish manufacturers. The inspected roofs are taken from a database of more than 15000 roofs under a warranty system for roofs in Denmark.

The warranty system was established in 1989 and was in full service in 1991 with approximately 1×10^9 m² of roofs added each year. The warranty period is 10 years and in that period less 0.5 percent of the roofs experience problems.

Please note that service life and warranty period are two different things and the expected (and experienced) service life time is fortunately much longer than the 10 year warranty period.

UV- radiation and heat from the sun is normally considered to be the main mechanism regarding ageing of bituminous roofing. To protect the surface of the membrane against UV-radiation it is normally protected by slate granules. It is of utmost importance that the uppermost protective layer is not damaged e.g., during the laying of the roof, from ice build-up or during maintenance in the service life of the roof.

The survey included a visual inspection of the roofing felt as such, the condition of the details and a subjective assessment on the remaining service life of the roof covering.

Besides specimens of the membrane were taken out from the surveyed roofs and the membranes were tested on the labs of the producers to detect any changes in properties during the use.

3.1 Visual Inspection of Roofs

The surveys were done according to an inspection list made for the purpose. The list included relevant information about the building owner, geographical position, etc. The technical evaluation was assessed as shown in the following example:

Roof covering:	2 ply SBS-modified bitumen Slope about 30°
When applied:	1991
Description:	The roof is made as a saddle roof with felting on angle fillets. The roof is build together with a lower low-sloped roof. This roof is assessed separately.

Visual inspection:

<i>Overall impression:</i>	Some deformations in the substrate (roof elements) are clearly visible. The roof covering itself looks acceptable.
<i>Granule covering:</i>	Generally good. "Surface cracks" on the west side of the building
<i>Tightness of welding seams:</i>	Ok
<i>Fastening:</i>	Ok
<i>Cracks in the roofing felt:</i>	Starting to appear on angle fillets
<i>Blisters:</i>	None
<i>Folds in the covering:</i>	None
<i>Cracks at flashings etc.:</i>	None
<i>Damage around roof lights:</i>	No rooflights
<i>Algae etc.:</i>	Some algae on north facing surfaces of angle fillets
<i>Valleys:</i>	No valleys
<i>Drain:</i>	The roof is drained over the edge of the roof
<i>Further remarks:</i>	None

Estimated remaining service life based on the visual inspection: at least 15 Years

Using the service life model for this roof gives the following result:
 $L = 50 \cdot 1 \cdot 1 \cdot 1 \cdot 1 \cdot 1 \cdot 0.9 \cdot 1 \cdot 1 = 45$ years.

Similar, the other roofs give in average results corresponding to the subjective assessment of the roof.

3.2 Laboratory Analysis on Test Samples

Laboratory tests on samples taken from the inspected roofs were performed by the 2 Danish producers in their own laboratories. The properties tested were those considered most crucial for a long service life. The roof membrane must remain watertight, weather-resistant and be able to resist influence from the underlying substrate.

All roofs are exposed to high temperatures in summer time and it is for that reason important that the bitumen is high quality and not sensitive to heat ageing. Temperatures of 70 to 80 °C can easily be reached on a hot summer day even in Scandinavia.

Table 1. Relevant properties for bituminous roofing.

Softening point/flow resistance	The flashings must be fastened so that they remain intact.
Cold bending:	The membrane must remain flexible in cold weather to resist traffic on the roof and the protective bitumen must not crack
Adhesion of the protective layer:	The membranes granule coating must remain intact to protect the bitumen from UV-radiation.
Tensile strength and elongation:	The membrane must remain flexible and be able to resist small movements in the substrate.
Shear and peel strength of joint:	The shear and peel strength of the joint must remain high to render the membrane watertight.

It is not possible to test the shear and peel strength of the joint on samples taken out from the roof as all roofs inspected are 2 layer systems. The results of the laboratory investigations were:

Table 2. Test results for the test samples taken from the surveyed roofs.
L = longitudinal, T = transversal.

Roof #	Tensile strength, L ¹	Tensile strength, T	Elongation, L	Elongation, T	Cold bending ²⁾	Softening Point	Adhesion of granules	Flow resistance	Year of Installation
1	1356	1030	45	53	-20	103,6	95	90	1992
2	1056	826	32	33	-8	99,4	95	80	1992
3	1196	836	49	48	-20	107,6	93	80	1993
4	1218	968	51	53	-20	105,7	94	90	1992
5	460	931	42	48	-6	122	97	100	1991
6	754	1025	41	36	4	91	97	70	1991
7	709	1082	45	46	-6	112	94	100	1991
8	734	970	43	38	-6	99	94	80	1991
9	714	957	41	35	-2	100	91	90	1991
10	641	679	39	40	4	89	92	70	1991
11	1167	1006	39	47	-2	115	94	100	1991
12	-	-	-	-	-4	109	-	100	1991
Sum	10005	10310	467	477	-86	1253.3	1036	1050	
Mean	909.5	937.3	42.5	43.4	-7.2	104.4	94,2	87.5	³⁾

¹⁾ It is difficult to see on samples what is parallel to production direction

²⁾ Cold bending is on the top side of the product

³⁾ Samples are taken in 2003

Table 3. Test results for the test samples taken from the surveyed roofs compared with the requirements.

<i>Properties</i>	<i>Test method</i>	<i>Unit</i>	<i>Requirement</i>	<i>Results from samples mean value</i>
Tensile strength, longitudinal	EN 12311-1	N/50 mm	500	909,5
Tensile strength, transversal	EN 12311-1	N/50 mm	500	937,3
Elongation, longitudinal	EN 12311-1	%	35	42,5
Elongation, transversal	EN 12311-1	%	35	43,4
Cold bending	EN 1109	°C	-20	
Cold bending after ageing	EN 1109/1296	°C	0	-7,2
Flow resistance	EN 1110	°C	100	87,5
Adhesion of granules ¹⁾	EN 12039	g/m ²	770-910	834,3
Softening point		°C	125 ²⁾	104,4

¹⁾ Amount of granules varies from 1100 to 1300 g/m

²⁾ No requirement, typical value

4 DISCUSSION AND CONCLUSION

Based on the findings from the visual inspections it is believed that well performing membrane roofs can be achieved provided that the above mentioned factors are taken into account when designing and executing the roof, i.e.:

- to obtain a good roof a high class roof covering is necessary,
- two plies will generally provide better protection than one layer,
- a roof with a well defined slope will eliminate/reduce the risk of ponding and decrease the time of wetness and the risk of ice building,
- the construction including the underlying substrate shall be stable enough to avoid deflections that may damage the roof covering,
- the roof shall be designed taking into account not only the constructions but also the installations and any complications that may arise due to the severe exposure to water and high relative humidity,
- the structure that supports the roof shall be stable enough to avoid deflections that may damage the watertight layer and the surface covering,
- the fastening shall secure the roof covering and must not cause unintended, increased load on the membrane itself,
- all details shall be well described/illustrated, easy to construct at the building site and preferably with a good use record (or tested for watertightness),
- pedestrian traffic should be avoided as far as possible or measures should be taken to protect the membrane from direct contact,
- the roof shall be maintained regularly--preferably on the basis of regular inspections and especially regarding details etc.

Undoubtedly the factors mentioned are crucial for the service life . The findings from the visual inspections and the laboratory tests seems to confirm that the service life model - at least for bituminous roof membranes - gives a good estimate of the service life.

It should be emphasized that the model is rough and with considerably uncertainties as some of the factors are based on individual evaluation.

The experience from the few problems in the warranty shows that it is often the details of the roof that fail – which is in accordance with the findings in the survey.

Therefore the service life time model should emphasize the use of correct details in the roof design more in order to secure against water infiltration etc. It is proposed that the model is improved by using a more detailed factor for design as shown below.

Details	No critical details ¹⁾	≤2 critical details per 100 m ² roof	≤10 critical details per 100 m ² roof	≤20 critical details per 100 m ² roof	>20 details per 100 m ² roof
Factor d	1.0	0.8	0.6	0.4	0.3

¹⁾ Critical details are details not in accordance with the design rules as stated in the Danish design guide for roofs or wrongly executed details, e.g., too close together to ensure watertightness. An example of a critical detail is a flashing with a height lower than the minimum height 150 mm as stated in the Danish design guide. In the table 1 m flashing is considered equivalent to 1 penetration.



Figure 1. Example on two roofs with different slope but same roofing felt. Both were assessed during the survey.



Figure 2. Example of a dead low-sloped roof with ponding water. Ponding water leads to a risk of reduced service life due to increased exposure of the roof membrane to moisture and freeze-thaw cycles.



Figure 3. Example on different penetrating details normally seen on a roof.



Figure 4. Superficial "cracking" in the bitumen on steep surfaces leads to reduced protection by the granules.



Figure 5. Example of ponding water in a valley. In this case the water remained in the valley almost permanently and, as a consequence, the protective granules were gone.



Figure 6. Sampling of specimen for laboratory testing.

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