

Longterm Field Studies and Residual Service Life Prediction of FPO Roofing Membranes

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ABSTRACT

The results of fields studies after 10, 15 and 20 years of roof exposure of FPO membranes from a European manufacturer will be presented as well as data from continuous monitoring of designated roofs. On-site roof inspections and laboratory testing of aged roof samples were used for the assessment of the durability of the polymer membranes.

The results of these studies are used as input for estimations of the residual service life of the membranes. The time dependant behaviour of the mechanical strength in comparison to standard design requirements is used for these estimations. The findings of these residual service life prediction procedures are discussed.

KEYWORDS

FPO, Roofing, Service life, Durability, Membranes.

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1 INTRODUCTION

The use of flexible polyolefin membranes in roofing has only been possible after the introduction of powerful light stabilisers. Hindered amine light stabilisers are accessible to roofing since the mid 1980's. First FPO roofs have been installed in 1988 in Europe. Full market introduction of FPO roofing membranes was in February 1991 in Europe and somewhat later in North America. Since then these roofing membranes have gained wide acceptance in the European as well as in the North American market place (Baxter [1998], Beer [1995, 1997], Foley [1997], Paroli [1999]). The common designation for this type of roofing membranes is FPO (flexible polyolefins) in Europe and TPO (thermoplastic polyolefins) in North America.

Durability of building materials is a key topic in building construction. When innovative materials are introduced to the market, well based predictions of their service life are of prime importance. Lacking track records, the extrapolation of data from accelerated ageing tests is the only means for meaningful predictions on the durability of the new products. At the time of the first test installations only such predictions could be used for the estimation of the material's durability. Based on the manufacturer's experience, comprehensive testing programs and a series of field tests which had begun in 1988, the service life of the new kind of membranes was predicted at several decades. Now, more than twenty years later, these assumptions can be verified. On the occasion of 20 years of field experience with flexible polyolefin roofs the manufacturer Sika commissioned in 2008 a third party testing institute (Wehrle [2009]) with the task of an expert report on the durability of their FPO membranes.

This testing institute had already carried out expert studies after ten and fifteen years of field experience with FPO membranes (Rieche [1999, 2004]). The results were presented to the roof waterproofing community (Beer [2000, 2008]). The overall assessment of these studies was very positive regarding the durability of the manufacturer's FPO roofing membranes. The fact that the observed deterioration of the material properties was only marginal supports the previous assumption of a service life of several decades.

2 METHODOLOGY

The investigation described here is based on a field study of roofing membranes on 139 roofs covered with Sarnafil T FPO membranes with fiber glass mat inner layer (referenced as G-type) for ballasted applications or with combined reinforcement of fiber glass mat and polyester scrim (referenced as S-type). The roofs inspected were exposed to Central European climate (no heat/desert or arctic extremes). It has to be noted that fire behaviour tests (external fire performance) are less severe in Central Europe than in other countries like USA or UK. Thus they contain a lower amount of flame retardents or even none (G-type), which may have a positive influence on their longevity. On behalf of the manufacturer the German Institute for Building Protection, Building Materials and Construction Physics (Wehrle [2009]) examined and evaluated four roofs of various age, taking into consideration the overall evaluation 139 roofs monitored by the manufacturer. A total of more than 200 samples of FPO roofing membranes with ages up to 20 years were collected and examined. The data of samples aged 13-20 years were collected from generation 1 products (PE base). The other samples are PP based. The roof assessment and testing of material samples of the four roofs was done by the institute independently of the manufacturer's surveys, according to the following criteria:

Roof assessments: General condition of roofing, roof assembly, flashings, welded seams, construction technology aspects were inspected and assessed on site.

Material samples: Laboratory testing included determination of thickness, tensile strength, elongation at break, low temperature flexibility, peel strength and shear strength of site-welded seams, and microscopic investigation of the membrane surface.

These properties are essential for predicting the durability of polymeric waterproofing membranes. By merging the data of the institute and the manufacturer the long-term stability and durability of FPO roofing membranes of types G and S can be predicted, supported by a broad base of data and using methods of accelerated artificial weathering. The longer the observation period and the larger the number of investigated roofs, the more reliable the data obtained through field investigation is for predicting service life. A more detailed discussion on providing a forecast in the product and system development phase has been presented by Beer [2000].

3 RESULTS

3.1 Roof Assessments

The on-site assessments of four roofs were performed by the testing institute. Roofs A and B were on industrial buildings in Germany. They were covered with mechanically attached S-type membranes. The membranes on roofs C and D were G-type with gravel ballast, located in Switzerland. Roof C was on a shredding and recycling company and roof D was on car parking garages.

All four examined roofs were found to be in good general condition (Figures 1-4). They were all fully functional and showed no signs of leakage or membrane deterioration. Soiled spots could easily be cleaned, even rust arising from metal parts (Figure 2). Edge securings, flashings at penetrations such as curbs (Figure 2) and skylights (Figure 3), corners and other details were intact. All seams probed with a screwdriver were tight. All sampling locations could easily be patched by hot air welding using the standard methods described in the manufacturer's installation guidelines (Figure 4).



Figure 1. Overview of roof A at Fellbach.



Figure 2. Curb flashing detail. Rust stains can easily be cleaned.



Figure 3. Overview of roof C at Flawil.



Figure 4. Closing of sampling area on roof C.

3.2 Laboratory Testing of Samples

In order to pool the characteristics of various polymeric waterproofing membranes in uniform terms, one can express the change of properties over time in relation to the properties of new material (value of sample after ageing divided by value of new material). A value of 1.0 means no change after ageing. This method was used for presenting the data in this paper.

Mechanical properties of new materials show a certain distribution of values, due to various technical aspects of production and measurement. This distribution of values can be quantified using standard deviation methods. For the graphic display a confidence interval of 99% was chosen. 99 out of 100 measured values of new material lie within the range of the indicated scatter band. If values measured on a sample from an exposed roof are within this confidence interval, this means that the material properties have not changed significantly compared to their initial value. Testing was generally done according to EN 13956 [2005].

Figures 5 and 6 show that ageing of both type of membranes up to 20 years has virtually no influence on the thickness of the membranes.

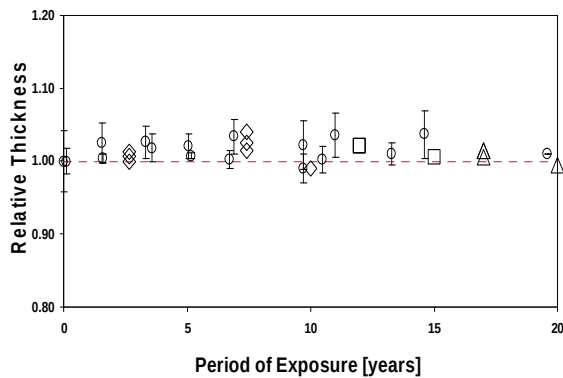


Figure 5. Thickness of aged G-type membranes.

- ◇ data from 1999 study by Rieche [1999]
- data from 2004 study by Rieche [2004]
- △ data from 2009 study by Wehrle [2009]
- manufacturer's data from 139 roofs, with 99% confidence band.

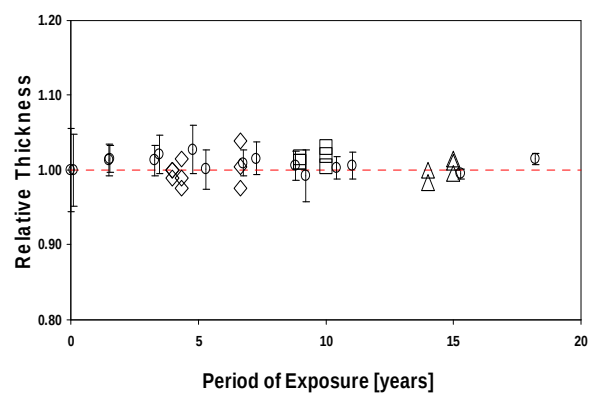


Figure 6. Thickness of aged S-type membranes. Legend as Figure 5.

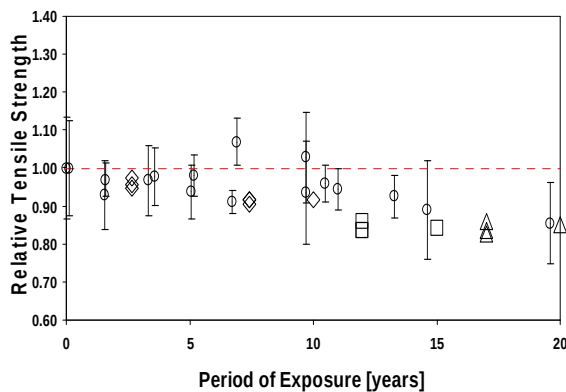


Figure 7. Tensile strength (longitudinal) of aged G-type membranes. Legend as Figure 5.

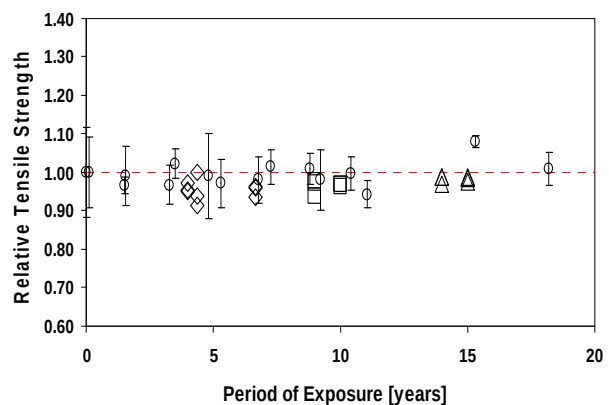


Figure 8. Tensile strength (longitudinal) of aged S-type membranes. Legend as Figure 5.

Figures 7-10 show the development of tensile strength and elongation at break of the membranes with increasing ageing duration. A slight decrease of the tensile strength over the period of 20 years can be

noticed in G-type membranes. No significant change was registered for the elongation at break. In G-type membranes the tensile strength and elongation at break are mainly determined by the properties of the polymer matrix. In S-type membranes these characteristics are governed by the properties of the embedded polyester scrim reinforcement.

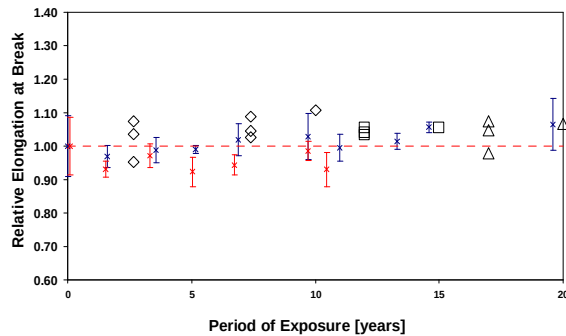


Figure 9. Elongation at break (longitudinal) of aged G-type membranes. Legend as Figure 5.

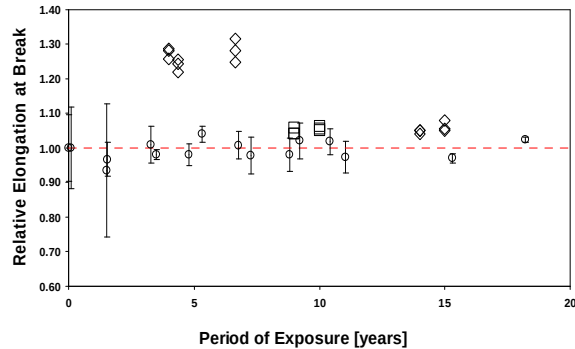


Figure 10. Elongation at break (longitudinal) of aged S-type membranes. Legend as Figure 5.

Elongation at break and tensile strength of S-type membranes did not exhibit any changes over the observation period of 18 years. The runaway values ($\diamond$) in Figure 10 were caused by a measurement mistake during the first expert study after 10 years (Rieche [1999]).

The shear and peel strength of seams were determined for both membrane types. The respective data did not exhibit any change from the original values..

All of the tested samples in the 20 year expert study (Wehrle [2009]) passed the low temperature folding test EN 495-5 at -30 °C. Five out of seven passed at -35 °C.

Microscopical examination of 20 year old samples of G-type, applied under gravel ballast, revealed no significant changes in comparison to unaged material (Figures 11,12).

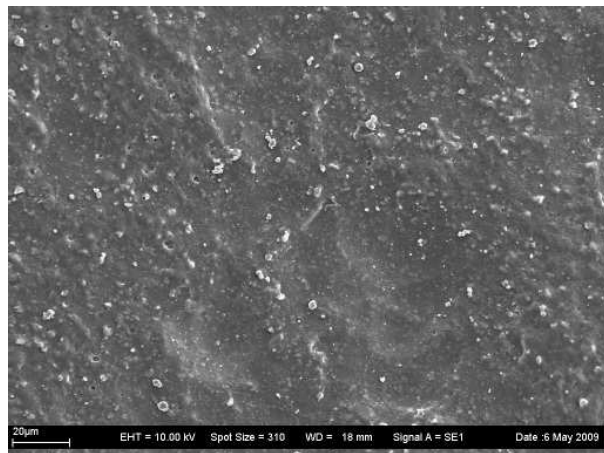


Figure 11. SEM photograph of surface of unaged G-type membrane.

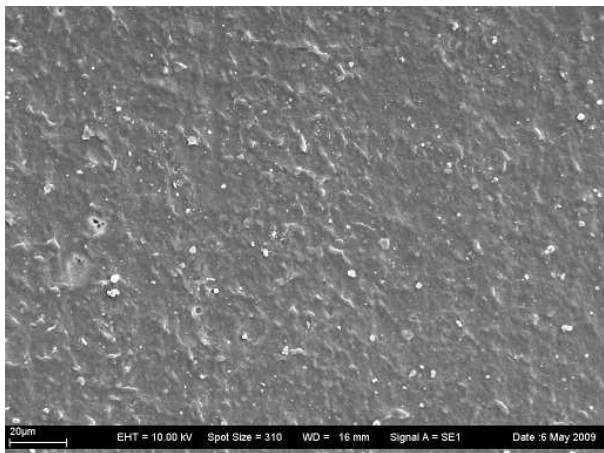


Figure 12. SEM photograph of surface of 20 year roof aged G-type membrane.

The surface of an S-type membrane aged for 15 years in sunlight exposed conditions shows some pollution particles but no degradation in optical microscopy (Figure 13). At higher magnification some faint and isolated crazing was detected (Figure 14). The length of the crazes was below 100 µm, the width 2 µm and the depth was estimated at 10-20 µm.

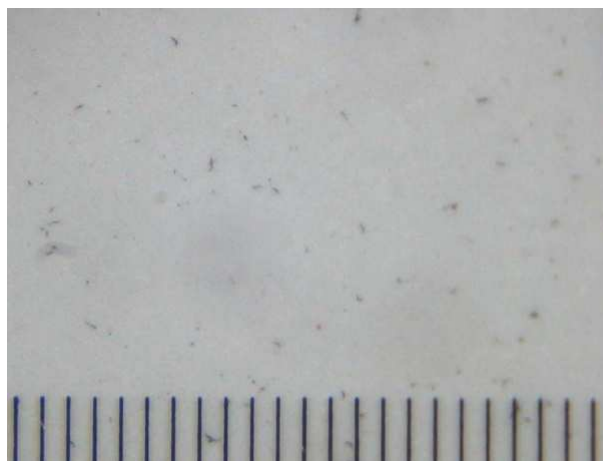


Figure 13. Surface photograph of 15 year roof aged of S-type membrane. Scale division is 1 mm.

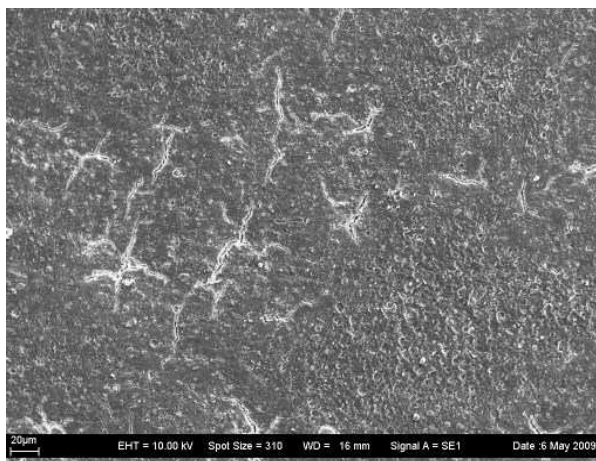


Figure 14. SEM photograph of surface of 15 year roof aged S-type membrane.

Only a small excerpt of all the collected data can be included in this paper. The data shown are a representative selection of all data. In most cases data of the oldest roof of each material type are depicted in this paper. Comparison of all mechanical data does not reveal differences between properties measured in longitudinal or cross direction of the membranes.

4. DISCUSSION

4.1 G-Type Membranes

The roofs investigated with G-type polymeric roofing membrane have been exposed for periods of 17 and 20 years. Thickness of the roof samples did not decrease over the observed period. The SEM inspection of the G-type sample showed no signs of surface changes after 20 years of roof exposure. Mechanical properties, such as elongation at break and flexibility at low temperatures, have not changed over the 20 years of service. All these facts are strong indicators that the material has not undergone significant degradation.

Aged welded seams had the same strength in shear and peel mode as new material. It is an important finding that properly welded seams are not affected by outdoor weathering and are still perfectly tight after 20 years. Another evidence of the non-degrading of the material is the fact that the sampling areas could easily be re-welded with fresh membrane pieces.

A slight reduction in the tensile strength of G-type membranes was observed. The decrease depends on duration of usage. Considering the results from the 15 year study (Rieche [2004], the last five years show a slower reduction of tensile strength in comparison to the reduction during the first decade.

Based on this time-dependent change of the tensile strength a rough estimation of the service life expectation of G-type membranes can be attempted. The membranes are subject to tensile forces arising from thermal expansion and contraction. With a thermal expansion coefficient of $35 \times 10^{-6} \text{ 1/K}$ and a temperature difference of 45 °C (+25 °C under application conditions, -20 °C in winter conditions) a length reduction of approximately 0.2% has to be taken into account. This dimensional change leads to a force of approximately 0.3 N/mm². The requirement of the standard DIN 18531-2 [2008] is an initial tensile strength value of 5 N/mm² for new roofing membranes. Model calculations based on data like in Figures 7 and 8 produce a period of 55 to 100 years before the tensile strength drops to 5 N/mm².

According to the manufacturer's long-time experience with mechanical attachments 1.5 N/mm^2 seem to be sufficient for dimensioning of the forces to be dealt with. Allowing for reduction of the above DIN requirement to 3 N/mm^2 after ageing this would still be a double safety margin with the regards to 1.5 N/mm^2 arising from experience and a six to ten fold safety margin with regard to the forces induced by thermal movement. The rough estimation with the 3 N/mm^2 produces a service expectation above 100 years. It needs to be clearly stated that such figures are based on experience data of maximum 20 years and represent theoretical extrapolations. They assume that no conditions during the extrapolated service life will change with regard to the practically experienced duration so far (e.g. no change of climatic conditions, no change in ageing mechanism, etc.). Additionally it is worth mentioning that the absence of flame retardents is believed to have a positive influence on the long term durability.

4.2 S-Type Membranes

The findings of the S-type membranes are mostly identical with those of the G-type membranes. Due to the embedded polyester reinforcement scrim they show no hint of deterioration in mechanical properties. Faintest surface crazes were found after 15 year outdoor weathering with direct exposure to sunlight. Ultraviolet radiation might have caused the crazes. Crazing is very faint, it cannot be detected by optical microscopy at up to 40 times magnification. In two out of seven samples the low temperature folding value was decreased from -35°C to -30°C .

Service life estimations for S-type membranes cannot be done the same way as with G-type membranes due to the reinforcement scrim. However, simple linear extrapolations of the data collected during 18 years suggest further service life expectations of at least the length of the so far experienced service years. However, the testing institute's and the manufacturer's investigations of S-type membranes show that the results of samples from roofs 14 to 15 years old lie within the scatter range of results obtained by internal monitoring of new materials, in other words, within the normal scatter ranges encountered in production. All specimens passed the low temperature folding test at intensified test conditions of -30°C . With the exception of two specimens (14 years old specimens), no test failures occurred even at testing conditions of -35°C . Thus the results of the present investigation confirm the data collected by the manufacturer for roofs up to 18 years old. The 1999 and 2004 durability assessments of S-type membranes are confirmed after additional 5 years by the results of this investigation on 20 years old membranes.

There are now two decades of proven, positive experience for the durability of S-type membranes of this manufacturer. The results suggest that the polymeric roofing S-type membranes will fulfil their waterproofing function for further decades, provided they are used in compliance with the application and maintenance requirements and conditions.

5. CONCLUSIONS

The results of this long term study and two decades of proven, positive experience with the type of the investigated FPO membranes suggest that these membranes will be able to fulfill their waterproofing function for further decades. However, this conclusion is restricted to the moderate Central European climate and does not hold for dramatic climatic changes and it assumes the exclusion of exceptional weather events and environmental impacts. Another precondition is the use of the membranes in compliance with the application and maintenance requirements.

No comparative investigations were made with membranes from FPO or TPO manufacturers in other regions. Experience shows that the performance of these kinds of membranes is strongly dependant on their specific formulation (Beer [1997], Carlson [2006]). Improper combination of raw materials and additives can lead to premature failure. Taking these considerations into account the authors

claim that the findings of this investigation are specific to the European FPO membranes examined in this study. An application of these findings to other types of FPO or TPO membranes and other regions is not appropriate.

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