FLEXIBLE POLYOLEFIN ROOFING MEMBRANES:TEN YEARS OF FIELD EXPERIENCE

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SUMMARY

Within the last decade flexible polyolefin roofing membranes have gained wide acceptance in the European as well as in North American market place. With over ten years of field experience in the background a European manufacturer of such membranes has carried out three different field investigations on existing roofs.

For the first project this report presents data gained from the constant monitoring of 42 roofs and a specific sampling and testing project carried out on 6 roofs by a testing institute. The roofs' age ranged between three and eleven years. Mechanically attached and gravel ballasted roofs have been considered. Properties such as tensile strength and elongation at break, low temperature flexibility, peel and shear strengths of the welded seams were determined, accompanied by surface examinations using optical and electronic microscopy.

The conclusions are that the investigated types of flexible polyolefin roofing membranes will fulfil their waterproofing and protection function for several more decades.

In a second investigation mechanical stresses induced by temperature cycles in the flexible polyolefin membranes were studied using finite element method analysis. The simulation calculations were run using material parameters determined from virgin material and from samples aged in the field. The results give evidence that material failure of flexible polyolefin membranes due to thermally induced stresses can be excluded.

In a third project the long term performance of field seams was studied. Provided proper seam preparation and welding techniques the long term functionality of the seams was proven.

ZUSAMMENFASSUNG

Abdichtungsbahnen aus flexiblen Polyolefinen Innerhalb des letzten Jahrzehnts weite Verbreitung im Europäischen und im Nordamerikanischen Markt gefunden. Mit über zehn Jahren Felderfahrung im Hintergrund hat ein Europäischer Hersteller solcher Produkte drei verschiedene Untersuchungen zur Langlebigkeit an bestehenden Dächern durchgeführt.

Bezüglich des ersten Projekts umfasst dieser Bericht hauptsächlich Daten aus der kontinuierlichen Überwachung von 42 Dächern und einem durch ein Prüfinstitut speziell durchgeführten Projekt der Probenahme und Prüfung bei 6 Dächern. Das Alter der Dächer reicht von drei bis elf Jahren. Einbezogen wurden mechanisch befestigte Dächer und Dächer mit Kiesauflast. Eigenschaften wie Zugfestigkeit, Reissdehnung, Flexibilität in der Kälte, Schäl- und Scherfestigkeit der Schweissnähte sind gemessen worden, begleitet von Oberflächenuntersuchungen mittels optischer und Rasterelektronenmikroskopie.

Die Schlussfolgerung sind, dass die untersuchten flexiblen polyolefinen Dachabdichtungsbahnen ihre Schutz- und Dichtfunktion noch einige weitere Jahrzehnte erfüllen können.
In einer zweiten Studie wurden durch Temperaturwechsel induzierte mechanische Spannungen in den flexiblen polyolefinen Abdichtungsbahnen mittels der Methode der Finiten Elemente untersucht. Die Simulationsberechnungen wurden mit Materialparametern von frischem Material und von gealterten Mustern von Dächern gefahren. Die Resultate zeigen auf, dass Materialversagen von flexiblen Polyolefinbahnen aufgrund von thermisch induzierten Spannungen ausgeschlossen werden kann.

In einem dritten Projekt wurde das Langzeitverhalten von Schweissnähten auf Dächern studiert. Unter der Voraussetzung sachgerechter Nahtvorbereitung und Schweisstechnik konnte die Langzeitbewährung der Nähte nachgewiesen werden.

RÉSUMÉ

Au cours de la dernière décennie, les membranes d'étanchéité en polyoléfines flexibles se sont largement répandues sur le

marché Européen et nord-américain. Fort d'un bagage de dix ans d'expérience sur le terrain, un fabricant Européen de tels produits a entrepris trois examens différents concernant la longévité sur les toits existants.

Concernant le premier projet ce rapport présente essentiellement des données issues du contrôle continu de 42 toits ainsi que d'un projet de prélèvement et de contrôle réalisé spécialement par un institut de contrôle sur 6 toits. Les toits ont entre trois et onze ans. Les toits à fixation mécanique et les toits avec gravier ont été intégrés dans le projet. Des caractéristiques telles que la résistance à la traction, l'élongation à la rupture, la flexibilité à basse température ainsi que la résistance à l'écaillage et au cisaillement des joints ont été mesurées, accompagnées d'analyses des surfaces au moyen de la microscopie optique et de la microscopie électronique à balayage.

Les conclusions tirées sont que les membranes d'étanchéité de toiture en polyoléfines flexibles examinées peuvent encore accomplir leur fonction de protection et d'étanchement pour quelques décennies.

Dans une deuxième étude, des tensions mécaniques induites par variations de température dans les membranes d'étanchéité en polyoléfines flexibles ont été examinées à l'aide de la méthode des éléments finis. Les calculs de simulation ont été effectués avec les paramètres de matériaux vierges et d'échantillons usagés de toits. Les résultats révèlent qu'une défaillance matérielle des membranes en polyoléfines flexibles due aux tensions thermiques induites peut être exclue.

Un troisième projet s'est penché sur les caractéristiques longue durée des joints sur les toits. A condition que les joints aient été préparés selon les règles de l'art et que la technique de soudure soit correcte, il était possible de prouver la fonctionnalité à long terme des joints.

RESUMEN

Las capas impermeables de poliolefinas flexibles han ganado una gran aceptación en la última decada en los mercados europeos y norteamericanos. Respaldado por más de diez

años de experiencia, un productor europeo de dichos productos ha realizado 3 investigacions diferentes sobre la longevidad en tejados existentes.

Por el primero proyecto este informe resume principalmente datos de vigilancia continúa de 42 tejados y un proyecto especial de toma y prueba realizado por un instituto de ensayos sobre 6 tejados. Los tejados tienen entre tres y once años. Se incluyeron tejados fijados mecánicamente y tejados cubiertos con grava. Las propiedades medidas fueron: resistencia a la tracción, alargamiento a la rotura, flexibilidad a bajas temperaturas, resistencia a la cizalladura y resistencia al pelado de las soldaduras. Además se examinó la superficie usando microscopios opticos y electrónicos.

Conclusión: Las capas impermeables de poliolefinas flexibles examinadas pueden cumplir su función de protección y de impermeabilización aún durante unas cuántas decadas.

En una segunda investigación se examinó el esfuerzo mecánico en las capas impermeables de poliolefinas flexibles inducido por cambios de temperatura usando el método de análisis de los elementos finitos. Los cálculos de simulación se hicieron usando parámetros de material en materiales nuevos y en materiales envejecidos sobre tejados. Los resultados demuestran que se pueden excluir fallos del material de capas poliolefinas flexibles por esfuerzos inducidos por temperatura.

En un tercer proyecto se estudió la longevidad de líneas de soldadura sobre los tejados. Siempre que se usen los preparativos y las técnicas de soldadura apropiados se podrá probar la longevidad de las líneas de soldadura.

1. Introduction

The subject of service life, and particularly its prognosis, is a crucial topic with regard to building products. Accordingly, sustained performance requires a service life which is as long as possible – together with the requisite knowledge about its forecast. Where the long-term behaviour of many conventional building materials is known, manufacturers are also asked to provide sound forecasts for service lives, particularly for new, innovative products and system solutions.

Flexible polyolefins are regularly applied for roof waterproofing purposes for almost a decade in the European as well as in the North American market place [1-8]. Taking into account the trial phase prior to market introduction more than ten years of field experience in roofing applications have now been gained with these materials. The common designation for flexible polyolefins is FPO in Europe, whereas they are named TPO (for thermoplastic polyolefins) in North America.

2. Ten years of field experience with flexible polyolefin roofing membranes

On the opportunity of having reached ten years of field experience a European manufacturer of FPO membranes has taken the chance to make an assessment of the performance of the membranes during this period and of future service life expectancy. For this purpose three separate field investigations, combined with laboratory testing and simulation calculations, have been carried out:

a) a general survey of 48 roofs

b) a specific investigation on the mechanical fatigue behaviour of FPO membranes combined with FEM simulations

c) a survey on the long term performance of hot air welded seems on roofs

Survey A) has been carried out together with the Institute of Building Protection – Building Materials and Building Physics, D-Fellbach [11,12].

Investigation B) was lead by the consultant company Wolfseher & Partner, CH-Adliswil [13].

Survey C) was undertaken in co-work with a large roofing contractor company [14].

In this report there is only room for survey A) to be described in detail. Investigations B) and C) are only touched briefly; comprehensive reports of these two investigations are given elsewhere [13,14]. All the investigated membranes were reinforced, either with a polyester fabric (subsequently called S-type membranes) or a glass fibre mat (subsequently called G-type membranes).

The results found by the third parties A)-C) on site and by laboratory tests were evaluated together with the results of the manufacturer's own tests (data from existing roofs gathered on a yearly basis and results of production quality control) carried out to examine the following aspects:

- Condition and properties of the polymeric waterproofing membranes on the roofs inspected compared with the results of self-monitoring by the manufacturer and his test results on samples taken from this year's current production.
- Comparison with the roof data obtained by the manufacturer.
- Estimation of the long-term protection and durability offered by the investigated S- and G-type polymeric waterproofing membranes.

3. Service life predictions for flexible polyolefin roofing membranes

3.1 Forecasts during the life cycle

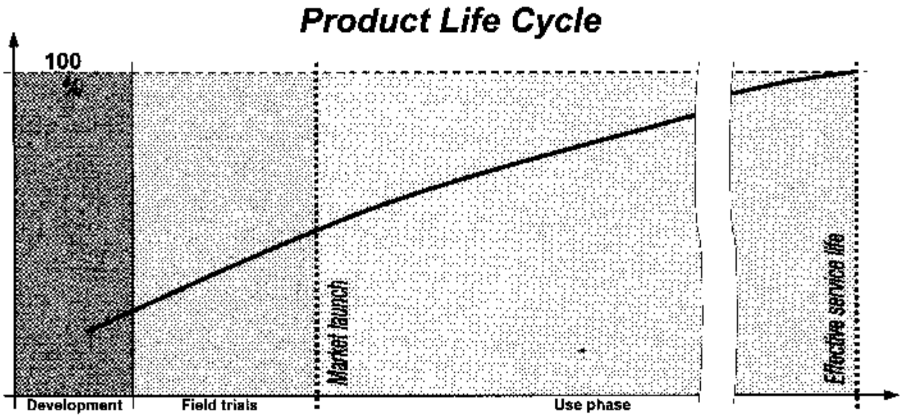

Figure 1: Product life cycle: changes to the reliability of a forecast during development and use.

Providing a forecast in the product and system development phase

Extended laboratory trials form the basis for the provision of a forecast for the service life of a product or system in the development phase. The use of accelerated ageing tests will show how the new product will respond to single or combined influencing factors to which the product will be exposed to during its subsequent utilisation phase. This data can be used to formulate an initial forecast. The reliability of this forecast can be increased if a phase of field trials is carried out where the product behaviour is tested under effective, application-specific influences, prior to a market launch of the new product. A 100% reliability is not possible in the product and system development phase. Accordingly, the customer must also trust that the manufacturer has carried out all the decisive tests, necessary preliminary investigations and checks.

Reviewing the forecast in the utilisation phase

The constant review of a forecast during the utilisation of the product is very important, particularly for long-life synthetic materials. Only after a comparison of product behaviour in actual use with its forecasted behaviour over an extended period will provide the customer and the manufacturer with the assurance that the forecast is correct. When carrying out field trials, the reliability of a forecast can be increased to 100% once the forecasted service life has been reached.

The example of the investigated flexible polyolefin roofing membrane shows how the forecast for its service has been reached and how this has been subjected to regular testing by external specialists. On the basis of the existing 10 years of practical experience, particular emphasis is given to the completion of field trials.

3.2 Estimating the service life of flexible polyolefin membranes during the development phase

At the time of project launch in 1988, the material class of flexible polyolefins FPO was new to the manufacturer's R&D staff, however not the desired application for flat roofs. In addition to this, the plastic class of polyolefins had been known for 10 years in the civil engineering sector.

The 25 years of expertise in the testing of roof and civil engineering waterproofing membranes, the experience with roofing systems and a knowledge of the requirements of standards was able to be directly used for the qualification of this new product. The following list shows a selection of the accelerated ageing tests, which, together with mechanical testing methods, continue to be used in laboratories for determining material behaviour:

- Thermal ageing (oven storage up to 130°C)
- Artificial weathering with UV irradiation
- Behaviour in (hot) water (up to 90°C)
- Hot-cold cycles (dry or in water)
- Behaviour in aggressive fluids (storage of chemicals)
- Resistance to micro-organisms (soil burial tests)

The new generation of waterproofing membrane was applied on selected roofs as early as 1989 and empirical data was gathered, so that a forecast for the service life would not have to rely exclusively on laboratory trials. Consequently at the market launch in 1991, an above-average service life was able to be forecast based on the results of wide-ranging laboratory tests, initial empirical results and the comparison with known waterproofing products.

The first external review of the forecast by Basler & Hofmann in 1992 [9] also confirmed that the investigated flexible polyolefin roofing membranes represented an ecological and economical high-quality solution, not only thanks to the use of innocuous raw materials and additives, but also on account of the long expected service life of these systems:

> "A product will result in a certain amount of environmental pollution during its life cycle. It is not only the sum of these environmental pollutants but also the time in which they occur which is decisive. The longer the life of a product, the smaller its environmental pollution per time unit. If it is possible to enlarge the time-span between production and disposal, then the environmental pollution per used time unit will also be reduced by an according amount. On the basis of

the tests carried out and the existing empirical data, it can be assumed that the studied flexible polyolefin roofing membrane can achieve a service life of approximately 40 years under normal conditions."

This first report [9], prepared for PE-based flexible polyolefin roofing membranes was updated for PP-based membranes in 1997 [10]. The experts came to equivalent conclusions as before.

3.3 Verification of the forecast after 10 years' field experience

On the basis of data gained from field experience, the reliability of a forecast can be considerably increased, as described in the section "Forecasts in the product life cycle". The 10 years of field experience with the European flexible polyolefin roofing membranes which was reached in 1999, provided sufficient grounds to review the forecast again, taking into account the wealth of practical experience gained from over 25 million m≈ of laid membrane, and underpin this on a wide range of field data. At this time the three afore-mentioned studies have been initiated.

4. Survey A: 48 roof inspections and roof monitoring

4.1 Procedure

The expert report described here is based on a field examination of S- and G-type roof waterproofing membranes for a total of 48 roofs.

This involved an examination and assessment of six roofs of different ages by the Institute for Building Protection (subsequently called "The Testing Institute"), to which were added the data for the roofs examined by the manufacturer, for the overall evaluation.

Thus a total of 82 roof waterproofing membranes samples (Figure 2) of type flexible polyolefin roofing membrane were successively removed and examined over a period of 10 years. The roof assessment and testing of material samples for the 6 roofs examined by the Testing Institute occurred independently of the manufacturer's tests in accordance with the following criteria:

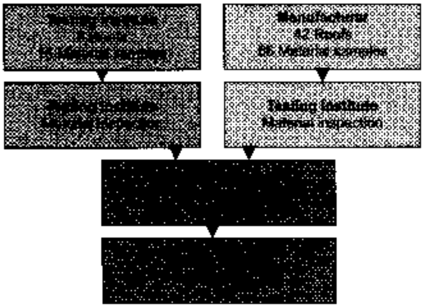

Figure 2: Data structure

<u>Roof assessments</u>:
General condition of roof, roof design, joints, welded seams, structural conditions

<u>Material samples</u>:
Thickness, tensile strength, elongation at break, folding at low temperature, peel and shear strength of on-site seams, microscopic examination of surface. These properties are of decisive importance for estimating the long term behaviour of flexible polyolefin roofing membranes.

The merging of data determined by the Testing Institute with the manufacturer's data allowed the estimation of long term performance and durability for the S- and G-type flexible polyolefin roofing membranes to be undertaken on a broad data basis.

4.2 Results

4.2.1. Roof assessments

All 6 examined roofs were found to be in a good general state. The edge attachment (Figure 4) and the connections to roof insertions such as roof lights (Figure 5) in particular were found to be in excellent shape. All the seams tested with a screwdriver were watertight. At all the removal points the membranes were able to be re-welded after up 11 years of ageing using the standardised procedure as per the processing guidelines.

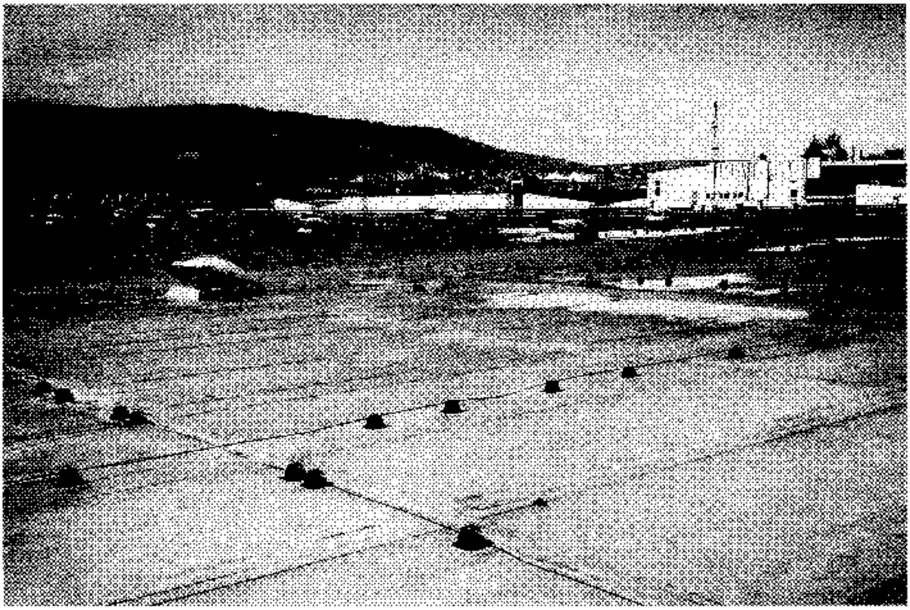

Figure 3: Overview photo of the roof surface of a roof in Waiblingen (Germany), age of roof: 8 years.

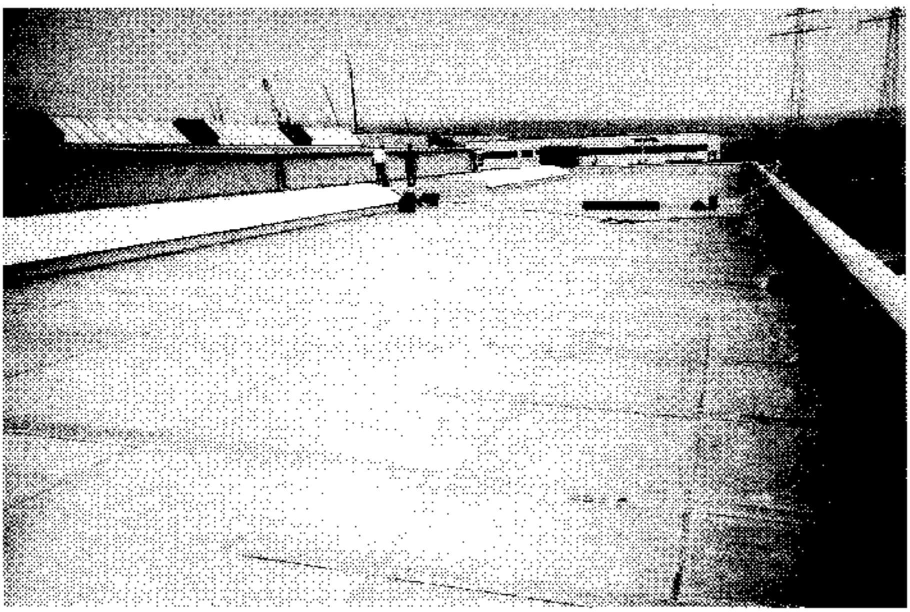

Figure 4: Overview of the roof surface and the parapet area of a roof in Ehingen (Germany), age of roof: 5 years.

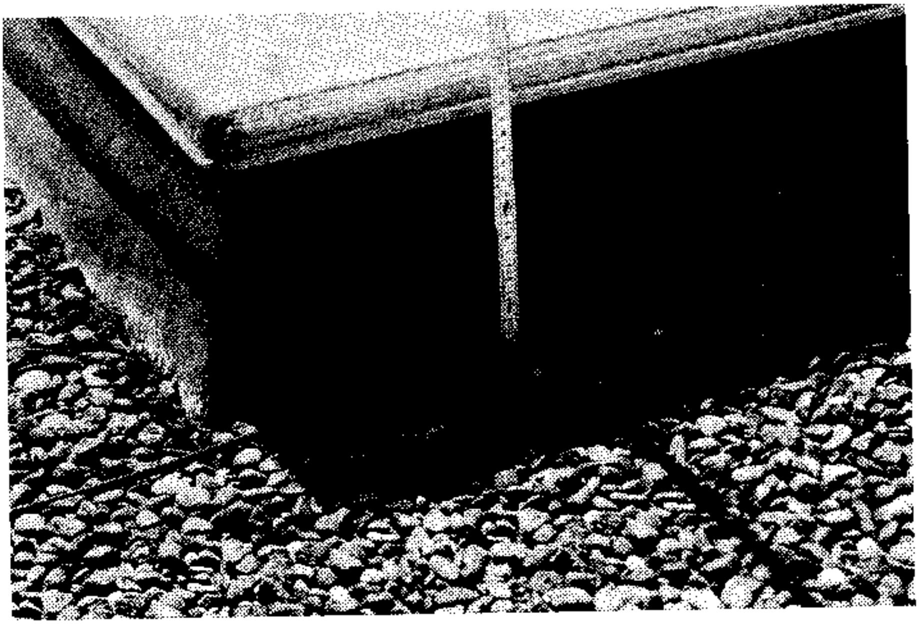

Figure 5: Connection to roof light at the shredding plant in Flawil (Switzerland), age of roof: 8 years.

4.2.2. Mechanical properties

In order to be able to summarise the properties of various flexible polyolefin roofing membranes in uniform depictions, the change of properties over time relative to the value of virgin material can be expressed. This method was selected in the expert report.

The mechanical properties of the virgin material show a scatter due to technical production and technical measurement reasons, which can quantified using a standard deviation. A 99% confidence interval was chosen for depiction in the graphics. Of 100 measurement values taken from the virgin material, 99 values were within this scatter range. If the measurement values after exposure also lie within this confidence interval, then the material properties have not changed considerably in relation to the virgin state.

The material tests on S-type flexible polyolefin roofing membrane showed that the mechanical values for elongation at break and tensile strength continued to remain within the above-described scatter ranges for virgin material, even with up to 10 years' exposure, and therefore no significant change in the properties exists. Figures 4 and 5 show the tensile strength of S-type FPO samples to represent this.

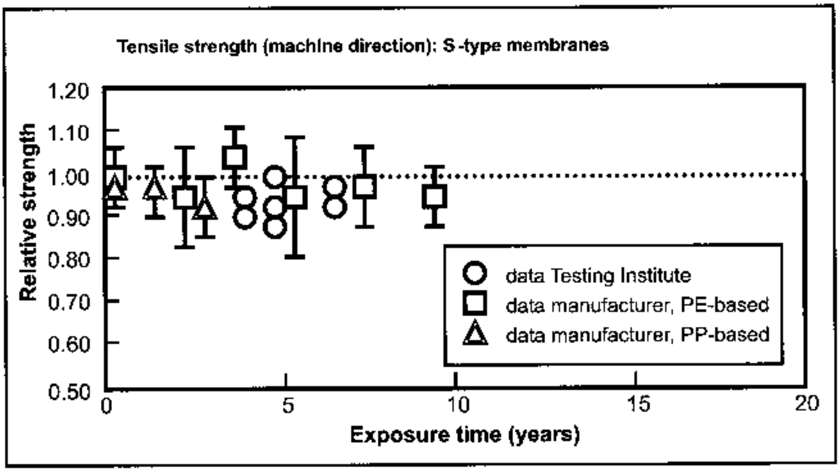

Figure 6: The tensile strength of S-type membrane in machine direction after exposure.

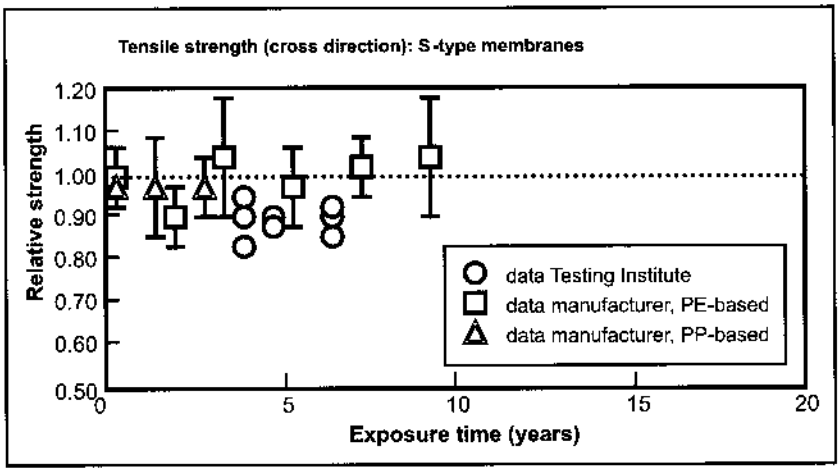

Figure 7: The tensile strength of S-type membrane in cross direction after exposure.

For G-type membranes the results for elongation at break and tensile strength were similar to those for S-type membranes, i.e.

a significant time-dependant change did not occur (Figures 8,9: elongation at break)

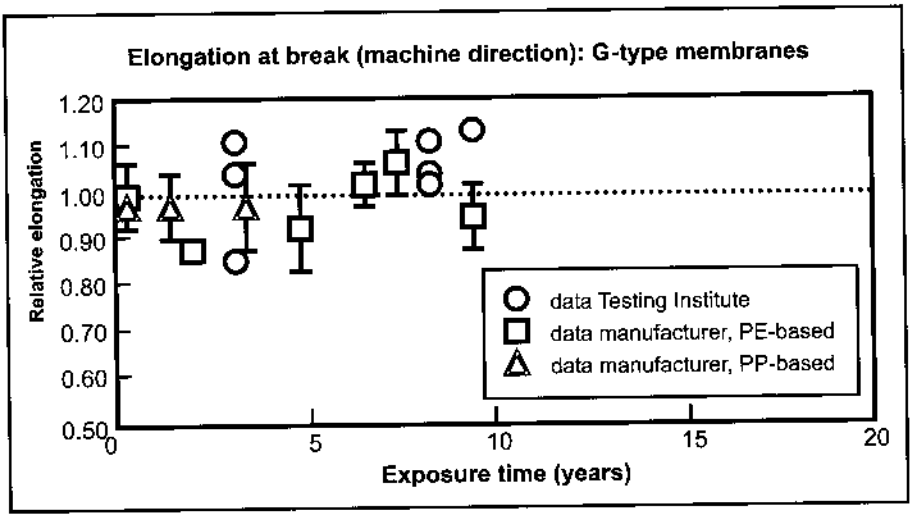

Figure 8: Elongation at break of G-type membranes in the machine direction after exposure.

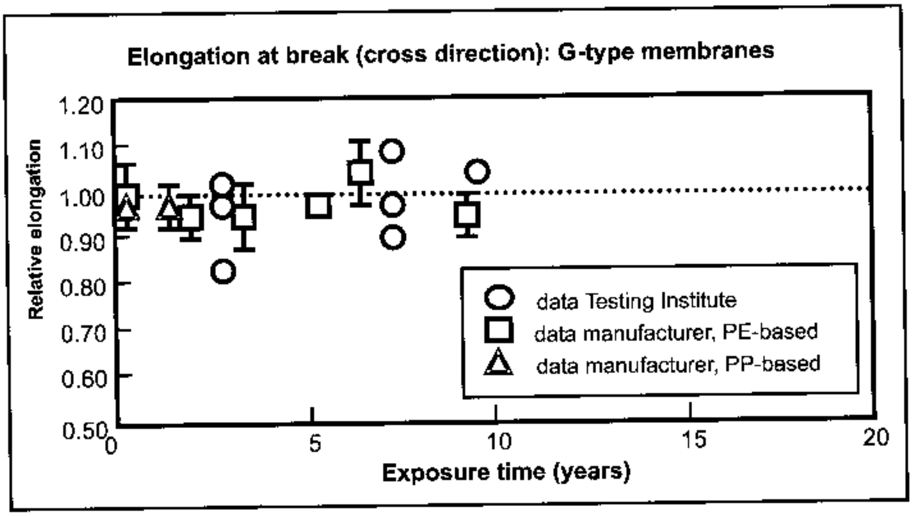

Figure 9: Elongation at break of G-type membranes in the cross direction after exposure

A certain degree of change existed in the measured values of elongation at break for G-type membranes. There was a tendency toward a once only reduction in tensile strength early on during ageing (Figure 10). The testing Institute can trace this back to a one-off swelling effect, which did not increase as a function of time. In spite of this effect, the measured values are still within the scatter ranger for virgin material.

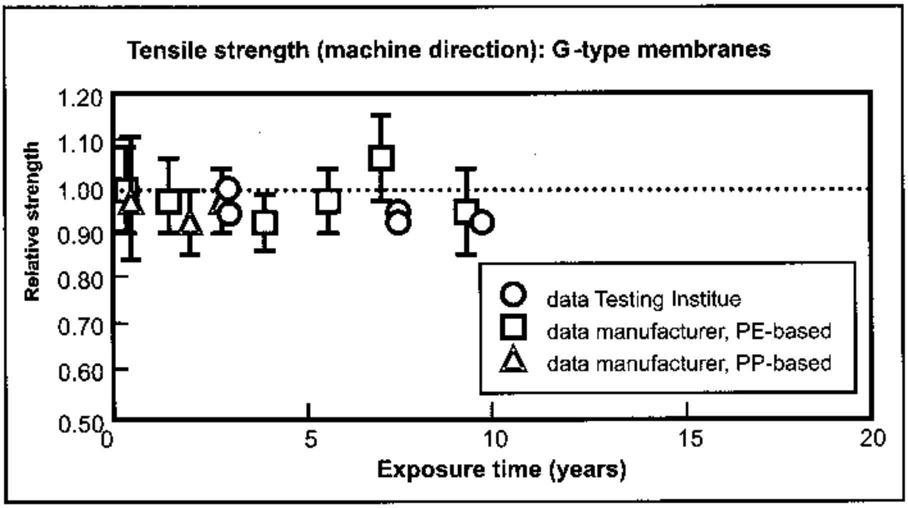

Figure 10: Tensile strength of G-type membranes in the machine direction after exposure.

4.2.3. Other properties

Both S- and G-type membranes showed no change in material thickness after the roof was subjected to stresses. The folding at low temperature revealed no cracks in spite of the increased severity of temperatures with regard to those specified in the standard [15] (-40°C instead of -20°C). The optical microscope examination at 30-fold magnification showed that no surface cracks were present. All of the welded seams tested tore outside the joint seams, as required in the standard.

4.3 Assessment of durability

<u>S-type flexible polyolefin roofing membranes</u>

The Testing Institute's investigations on the S-type flexible polyolefin roofing membranes showed that the test results of samples taken from 5, 6 and 8 year old roofs fell in the same scatter range as those from in-house testing, i.e. within the normal ranges required during production. This means that no change in the technical properties of S-type flexible polyolefin roofing membrane aged between 2 and 10 years was determined. There is also no indication of any tendency. This lead the Testing Institute to the conclusion that the S-type flexible polyolefin roofing membranes will be able to fulfil their function for at least several decades.

G-type flexible polyolefin roofing membranes

The roofs having G-type flexible polyolefin roofing membranes investigated by the testing institute were aged 3, 7 and 10 years. For many of the tested properties similar results were found as for S-type membranes, i.e. a significant time-dependant change was not able to be verified. A certain amount of change was observed for tensile strength though. When evaluating the results it must be borne in mind that the 10-year old sample was produced on a pilot plant, giving any extrapolations concerning later production only limited validity. If this is taken into account, then a 10% reduction in tensile strength over 10 years needs to be reckoned with.

However, the results show that a gradual reduction does not necessarily occur. There is a tendency for a one-off reduction in tensile strength at an early age. No further reduction in tensile strength occurs after this initial loss.

When the Testing Institute's results for G-type membranes are examined together with those coming from the manufacturer no significant time-dependant changes become evident. Therefore the testing Institute came to the conclusion that the G-type flexible polyolefin roofing membranes will be able to fulfil their function for at least several decades.

S- and G-type flexible polyolefin roofing membranes

During the object examinations it became evident that damaging influences on the S- and G-type flexible polyolefin roofing membranes arose when these membranes were subjected to direct contact with fresh bitumen compounds.

5. Study B (FEM): Mechanical failure induced by thermal stresses

The finite elements method of (FEM) forecasting gives engineers a powerful tool with which the most complicated problems can be solved mathematically.

Defining the stresses which a waterproofing membrane on a flat roof is subjected to is a complex task which can be modelled using the FEM method. As a result, calculations for gravel-ballasted roofs using G-type membranes were carried out in 1999 by Wolfseher und Partner AG allowing statements to be made concerning the thermally-conditional stresses and deformations in the roof waterproofing membrane as a function of the service life [13]. The temperature and service life-dependant material properties for G-types G-type flexible polyolefin roofing membranes (PE and PP based) were determined by Wolfseher und Partner AG and incorporated in the mathematical calculations. The calculation results led to the following conclusion:

"Based on the completed investigations, material tests and FE calculations the product can be described as relatively good and its service life given as a reliable approximation. Based on the description of the maximum loading with regard to stresses and elongations and the actual property changes caused by the exposure duration, it can be stated with a high degree of certainty that a life expectancy of 50 years can be reached, and most likely even exceeded, for both G-type flexible polyolefin roofing membranes (PE and PP based)."

6. Investigation C: Durability of welded seams

In this project the manufacturer and a roofing contractor cut out samples from 30 existing roofs. All the samples were of PP-based G-type flexible polyolefin roofing membranes, of thickness 1.6 mm, ranging between 1 to 5 years of age. On each roof samples with seams in machine and cross direction as well as T-joints were taken. Each sample set contained seams prepared by hand welding and by automatic welders. This lead to a total of 212 test specimens. Seam strength was measured in shear and peel mode according to the standard SIA 280 [15]. On none of the roofs any leaks were reported. However, some of the T-joints did not pass the SIA 280 vacuum bell test. It showed up that in these cases of insufficient T-joints the edge tapering prescribed by the manufacturer had not been done.

One hand welded seam in machine direction did not fulfil the standard requirements. It was evident that no seam preparation had taken place and that the seam was welded at far too high temperature settings. All other linear seams – hand- or automatic welded – did fulfil the SIA 280 requirements.

The results give sound evidence that well-done seams retain their full functionality over the service life period.

7. Uniformity of forecasts

The various presented investigations by external specialists confirm similarly the prognosis given in 1991 during the market launch, that the investigated products fully satisfy the stringent requirements regarding durability for flexible polyolefin roofing membranes and that the manufacturer's flat roof systems will achieve an above-average service life.

To be able to achieve an above-average service life for a roof system not only requires a flexible polyolefin roofing membrane which has been developed with care and expertise. Proper planning and construction of the roof, as well as regular inspections and maintenance work where necessary, are also decisive factors.

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