DURABILITY OF PVC ROOFING AND WATERPROOFING MEMBRANES – CASE STUDIES AFTER 40+ YEARS OF EXPOSURE

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ABSTRACT

PVC membranes have been in use since approximately 50 years. The paper describes three case studies of plasticized PVC sheets in roofing and tunnel waterproofing with exposure durations of more than forty years.

Case 1 is a roofing membrane produced in 1967. It was applied in fully adhered mode on a hydropower station in the southern part of Switzerland. This membrane is still functional after 45 years in direct weathering exposure. Samples were collected in 2001 and 2012. Although some degradation was found, the mechanical properties of this membrane remain on a level that it will fulfill its function for several more years.

Case studies 2 and 3 report on PVC sheets collected from two road tunnels in Switzerland after 41 and 44 years of use. Testing was done in cooperation with the Technical University of Cologne. The membranes had marginally aged. The mechanical data are still above the requirements for new membranes. Contemporary tunnel construction is based on the assumption of one hundred years of service life. The measured data suggest that this assumed period will be reached by the membranes with high probability.

1 INTRODUCTION

The patent for the industrial production of PVC was granted in 1913. However, membranes for roofing and waterproofing applications based on plasticized PVC are in use since the early 1960's only. Publications on the durability of such membranes are scarce, especially reports from the early years of application.

A comprehensive field study on 25 roofs in North America and 20 roofs in Europe was conducted in 2001/2002 and reported with various aspects (Graveline et at. [1], Whelan et al. [2], Cash [3] and Beer et al. [3,4]). Some papers on the hail resistance of aged PVC membranes were published by Cullen [6], Fricklas [7], Foley et al., [8] and Beer et al. [9].

One of the roofs of the 2001 study was revisited in 2012. The results of this meanwhile 45 year old roof are dealt with in case study 1.

For tunnel waterproofing no publications on applications twenty years or older could be found. This is understandable since tunnels have a design service life of one hundred years and access to the waterproofing membrane is almost impossible once a tunnel is finished. Due to security updates of two road tunnels of age 41 and 44 years samples could be collected. The results are presented in cases studies 2 and 3.

2 CASE STUDY 1 – A 45 YEAR OLD PVC ROOFING MEMBRANE

The roof of the hydropower station Nuova Biaschina at Personico/Switzerland was covered with a membrane of plasticized PVC with a fiber glass mat reinforcement. It was produced in 1967 and applied in fully adhered mode with a contact adhesive (Figure 1). A first sampling took place in 2001. The results of the subsequent lab testing were reported earlier [4].

In a second sampling in 2012 pieces of 1m by 1m were cut out and the sampling area was recovered with a freshly produced piece of membrane. Joining the 45 year old membrane with the new one by means of hot air welding was possible without any difficulty (Figure 2).

Figure 1: Hydropower Station Nuova Biaschina at Personico/Switzerland.

Figure 2: Over-welding the sampling area with a new piece of membrane.

The sample was tested at the original manufacturer's R&D center. The results of this testing are depicted in Figures 3-8 with initial values and data after 34 and 45 years respectively.

Thickness is reduced gradually from 1.2 mm to 1.04 mm (Figure 3, EN 1849-2). This goes in parallel with plasticizer reduction to 63.4% compared to the initial content (Figure 4). This loss of plasticizer leads to some stiffening of the membrane which reflects in the shift of the low temperature folding from -20°C to 5°C (Figure 5, EN 495-5). The 45 year value of this cold flexibility property did not change compared to the 34 year value. Dynamic puncture resistance was reduced from the initial 450 mm falling height of the impact tool to 300 mm after 34 years and stayed then constant after 45 years (Figure 6, EN 12691). The 300 mm represent the standard requirement for new membranes.

In tensile testing the elongation at break was reduced from 220% to 100% (Figure 8, EN 12311-2/B). Although this reduction is significant the membrane can still be elongated by double of its length until it breaks. This drop can be explained by the reduced flexibility. On the other hand the flexibility reduction leads to an increased tensile strength (Figure 7).

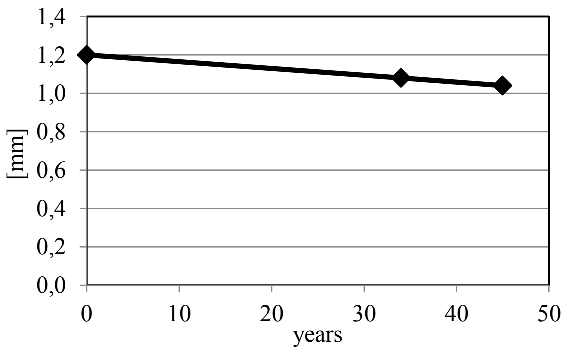

Figure 3: Thickness as f(time).

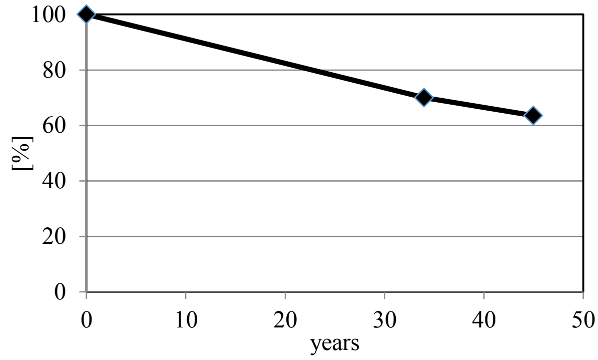

Figure 4: Plasticizer content as f(time).

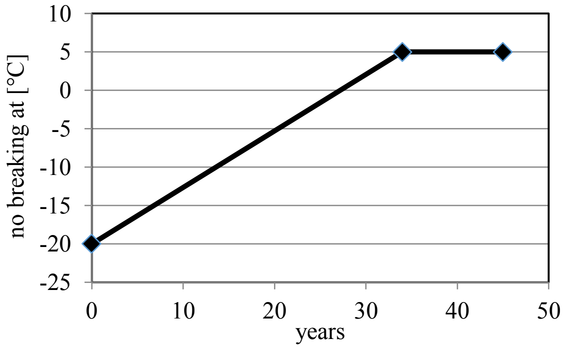

Figure 5: Low temperature folding as f(time).

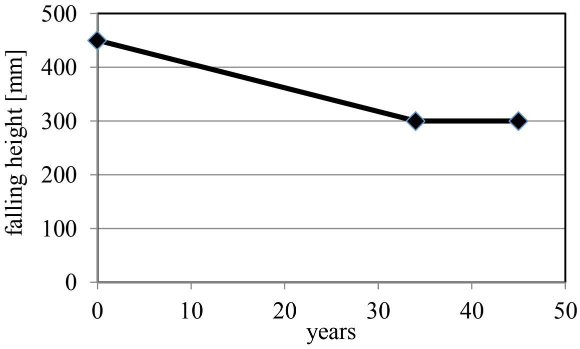

Figure 6: Impact resistance as f(time).

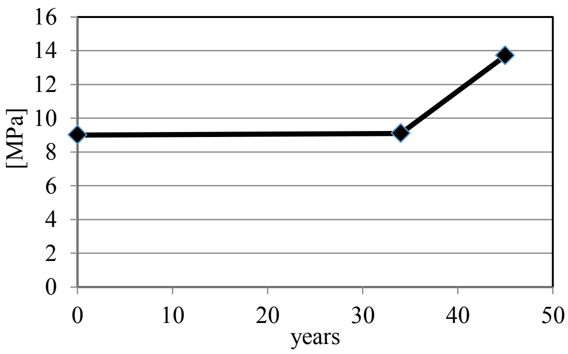

Figure 7: Tensile strength as f(time).

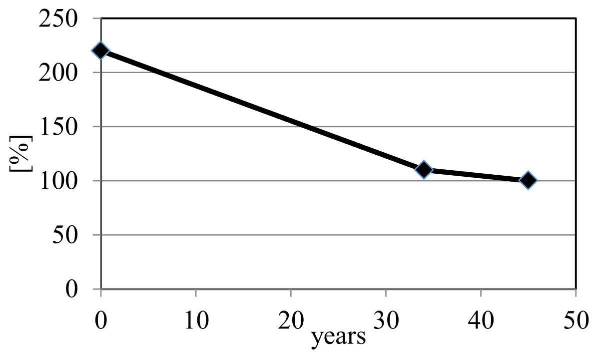

Figure 8: Elongation at break as f(time).

3 CASE STUDY 2 – A 41 YEAR OLD PVC TUNNEL MEMBRANE

The Tunnel Reussport is part of the highway bypass of the city of Lucerne in the center of Switzerland. It is integrated into the E35, a European main traffic axis North-South from Benelux and Germany to Italy. This bypass is one of the most frequented highway sections in Switzerland. Every day about 85’000 vehicles pass the tunnel It is a 600 meters long mining tunnel and consists of twin tubes with three lanes each. The tunnel has a rock superstructure of up to 30 meters in an urban area. It was built in 1970 in the partial waterproofing style, i.e. the umbrella type with water drainage along the tunnel side but without bottom waterproofing (Figure 9).

Due to some heavy accidents all the alpine tunnels are being refitted to comply with increased security requirements. One of them is the creation of person escape ports (Figure 10). At the occasion of such excavations the tunnel waterproofing membrane was accessible and samples could be collected.

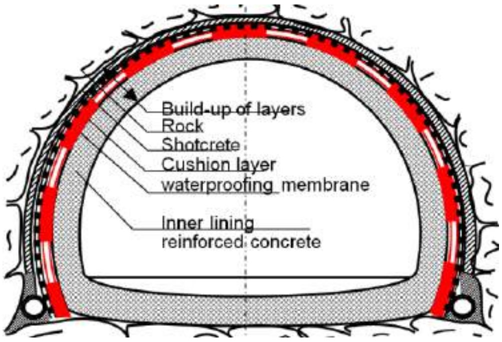

Figure 9: Schematic build-up of Tunnel.

Figure 10: Excavation of escape port in the Reuss- the Reussportport Tunnel.

The refurbishment started in 2009 and was finished in June 2013. The waterproofing membrane is a single ply membrane made of PVC-P and contains a glass fleece inlay. Its thickness was originally 1.5 mm. It is semi-transparent with a beige color. The samples received were visually in good condition although traces from stone indentations could be found on the bottom side of the membrane. The membrane had been manufactured in 1970. A retain sample of that particular production was still available for comparative testing with the aged sample from the tunnel. Apart from some holes and scratches arising from the excavation procedure the samples were in a very good state with surprisingly high flexibility.

The samples were tested at the University of Applied Sciences, Cologne/Germany and at the manufacturer's R&D center. Results and their discussion are presented in sections 6 and 7.

4 CASE STUDY 3 – A 44 YEAR OLD PVC TUNNEL MEMBRANE

The tunnel Allmend, Thun, is part of the highway A8 connecting the city of Berne with the City of Lucerne (Switzerland). It was built in 1968 in open cut construction mode. It underpasses a military training ground. The tunnel Allmend consists of twin tubes of two lanes each and is 960 m long (Figure 11). Although subject to a first refurbishment in 1991 the tunnel is partially damaged due to its service life of 45 years and requires renovation as well as new security installations. During the planning phase of the refurbishment project samples of the waterproofing membrane were taken by an engineering company to evaluate their actual condition. The engineering consultants handed over membrane samples to the manufacturer for in-depth analyses after 44 years of successful and damage-free service life.

The membrane was manufactured in 1968. It is of black color (Figure 12). As with the Reussport Tunnel a retain sample from that time is available (Figure 7). Six samples of size A3 were received and were tested by the same laboratories as in case study 2 above. The samples are reinforced single ply membranes made of PVC-P, the reinforcement consisting of a fine polyester mesh. They do not show any damage and are in very good and flexible condition.

Figure 10: Portal of the Allmend tunnel.

Figure 11: Sample from the Allmend tunnel.

5 TEST PROCEDURE CASE STUDIES 2 AND 3

The samples from the Reussport tunnel contained traces of adhering concrete on the backside. For testing purposes areas with low concrete residues were used and the residual concrete was removed. Samples from both tunnels were tested according to actual European standard procedures.

The ability of welding to new membranes was determined by hot air welding samples of PVC membranes from the two tunnels to fresh membrane pieces as actually provided to the market (Figure 12). After cooling down of the seams their strengths were tested by peeling. The criterion of a good seam is that break occurs not within but outside the seam.

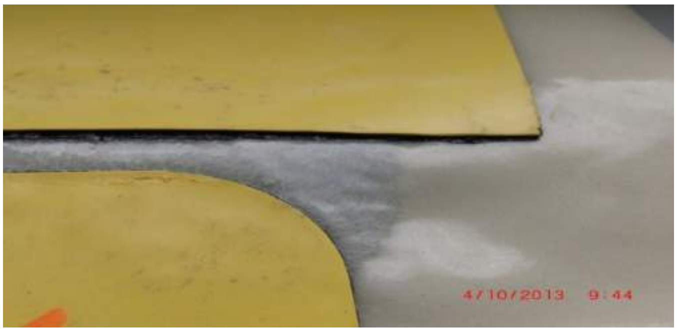

Figure 12: Two types of new membranes heat welded to a sample from the Reussport tunnel.

The results of the sample testing from both tunnels are listed in Tables 1 and 2. All tests were carried out using EN standard test methods with the exception of the plasticizer content determination which is an internal test procedure of the manufacturer.

6 TEST RESULTS CASE STUDIES 2 AND 3

Table 1. Properties of Samples from Tunnel Reussport

Property	Test Method	Requirement[1)]	Retain Sample 1970	Sample From Reussport Tunnel
Thickness	DIN EN 1849-2	-	1.50 mm	1.25 mm
Tensile Strength	DIN EN ISO 527-3	12 MPa [1)]	17.0 MPa	15.8 MPa
Elongation at Break	DIN EN ISO 527-3	> 250 % [1)]	300 %	278 %
Impact Resistance	DIN EN 12691 Method A	750 mm [1)]	1'000 mm	750 mm (2/5 1'000 mm)
Folding at Low Temperature	DIN EN 495-5	- 20 °C [1)]	- 20 °C pass	- 20 °C pass
Water Tightness	DIN EN 1928	no leakage at 10 kPa/24h [2)]	pass	pass
Plasticiser Content	Manufacturer's Test	-	100 %	91.1 % [3)]
Seam Test with New Membrane	DIN EN 12316-2	break outside of seam [1)]	pass	pass

Table 2. Properties of Samples from Tunnel Allmend

Property	Test Method	Requirement[1)]	Retain Sample 1968	Sample From Allmend Tunnel
Thickness	DIN EN 1849	-	1.45 mm	1.17 mm
Tensile Strength	DIN EN ISO 527-3	12 MPa [1)]	17.5 MPa	17.5 MPa
Elongation at Break	DIN EN ISO 527-3	> 250 % [1)]	240 %	226 %
Impact Resistance	DIN EN 12691 Method A	750 mm [1)]	1'000 mm	750 mm (4/5 1'000 mm)
Folding at Low Temperature	DIN EN 495-5	- 20 °C [1)]	-30 °C	-20…-25 °C
Water Tightness	DIN EN 1928	no leakage at 10 kPa/24h [2)]	pass	pass
Plasticiser Content	Manufacturer's Test	-	100 %	87.7 % [3)]
Seam Test with New Membrane	DIN EN 12316-2	break outside of seam [1)]	pass	pass

[1)] Requirements by ZTV/ING, [2)] Requirements by SIA V280, [3)] value vs retain sample

7 DISCUSSION

7.1 Roofing Membrane

The 45 year old roofing membrane was found to be in a satisfactory state – still fulfilling its waterproofing function without any leakage after this extended period of outdoor exposure. A significant feature is the fact that the sampling area could be closed without difficulty by re-welding a new piece of membrane onto the aged membrane. This is important because it ensures that possible mechanical damages to the aged membrane could be patched.

Over the whole exposure period the membrane has lost plasticizer and thus has become less flexible compared to its initial state. This reflects in lowered values of thickness, elongation at break and low temperature flexibility. On the other hand the tensile strength has increased.

Despite the aged state the membrane still has flexibility, mechanical properties and the ability to over-weld that give no indication for replacement in the near future. The course of the aging process as depicted in Figures 3-8 suggests that this membrane will fulfill its function for a service life for several more years.

7.2 Tunnel Membranes

After 41 and 44 years the two tunnel membranes showed very minor signs of aging. Still between 87 and 91 percent of the original plasticizer load is retained. The mechanical properties are remarkably high and exceed with one exception the state of the art requirements for new membranes. The exception is the elongation at break of the Allmend sample. However, in this case the retain sample from 1968 had an elongation of 240% which is slightly below today's specification of 250%. The aged sample had an elongation value decrease of 6 percent only.

The mechanical data after more than forty years in the tunnel can be regarded as good as new. Taking this and the easy re-welding ability into account it can be expected that these membranes might have a service life of several more decades.

A more detailed report on these tunnel membrane examinations is given in [10].

8 CONCLUSIONS

This study gives evidence that properly formulated and applied PVC membranes can have service lives clearly beyond forty years.

Roofing and tunnel membranes made of plasticized PVC with on-site service lives of more than forty years have been investigated. All membranes are fully functional and can be joined to new membranes by hot air welding.

The examined roofing membrane shows signs of aging after 45 years of direct weathering exposure. The course of aging and the still good state of the membrane lead to the conclusion that it will at least reach a service life of fifty years.

The outstanding condition of the two PVC tunnel membranes after 41 and 44 years of real exposure in tunnels leads to the conclusion that they have hardly aged. Consequently the still excellent functionality of these products has brought the engineers of the two tunnel upgrade projects to the conclusion that a replacement during the tunnel renovation was not necessary.

Unlike other material classes that show rapid decay after long phases of almost no deterioration PVC membranes possess the fastest decrease of properties in the first years of application. This initial decrease is followed by an exponential slow down. Based on this practical experience it does not seem presumptuous to assume on the basis of an exponential degradation slow down that these tunnel membranes can meet the actual design expectation of 100 years of service life for tunnels.

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