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Testing Joints of Air and Vapour Barriers, Do We Use Relevant Testing Methods?

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Abstract. *This article describes testing of peel and shear resistance and airtightness of joints of air and vapour barrier systems before and after artificial aging. The testing of peel and shear resistance was based on standardised methods while the test of airtightness was a method invented for this project. The results show that while peel and shear strength increased with aging, the airtightness was significantly reduced. As these two results seem to contradict each other, the methods are discussed, especially whether the standardised tests are too far from the conditions on site or joints should be tested on other materials as well. Furthermore, weaknesses in the airtightness method is also pointed out.*

Keywords: *Peel Resistance, Shear Resistance, Airtightness, Artificial Aging, Air and Vapour Barrier.*

1 Introduction

To reduce energy consumption some building regulations (*e.g.* BR18, 2017) require test of airtightness in newly erected buildings. Membranes are widely used to ensure the required airtightness but often their purpose is twofold; increased airtightness and reduced diffusion. Independently of whether a vapour barrier or an air barrier is needed, the tightness of the joints is crucial. Furthermore, the joints must stay tight throughout the service life of the membrane.

By joints are meant joints between two lengths of membrane and joints between membrane and other building parts. Tapes or adhesives can be used as sealants, most manufacturers sell membranes and sealants as systems, preferably including collars for pipes that may penetrate the membrane. This is a way to ensure that membrane and sealant are compatible. In Denmark, an independent company (DUKO) classifies vapour barrier systems and roofing underlays, the requirements for obtaining classification include tests of peel and shear resistance.

There are different standardised ways to test joints, *e.g.*:

- Peel resistance according to EN 12316-2:2013 or E DIN 4108-11:2016
- Shear resistance according to EN 12317-2:2010 or E DIN 4108-11:2016

Systems can be tested just after installation or after ageing. Although tests of airtightness are only required in new buildings, evaluation of durability requires tests of performance of aged joints. Methods for artificial aging are described by Møller and Hansen (2017), together with detailed descriptions of resistance test methods and a new way of testing airtightness.

This article describes the outcome of tests of resistance against peel and shear of nine vapour or air barrier systems before and after aging and the result of the non-standardised test of airtightness. It also discusses whether the result from standardised test methods corresponds to what can be observed on building sites and the new way of testing airtightness.

2 Method

All test methods are based on the standardised methods described in ISO or DIN standards except for the test of airtightness, which has been invented for this project. To ensure a uniform pressure when taping the joints, samples for peel or shear resistance testing were placed on a plane surface and a 50 mm wide 2 kg rubber coated roller was pulled over the joint.

2.1 Materials

Nine air or vapour systems were selected for testing, the selection was made by contacting manufacturers and suppliers of air or vapour barrier systems. It was asked whether they would be interested in having their product tested. The characterisation of the materials as given by the manufacturers is shown in Table 1. All systems used tape for joints.

Table 1. Materials used for testing with descriptions given by the manufacturers, VB and AB denotes Vapour Barrier and Air Barrier, respectively. PE = Polyethylene, PP = Polypropylene.

ID	Description	Membrane material	Thickness [mm]
A	VB	PE	0.11
B	VB	Multi-layer PE	0.20
C	VB	LDPE	0.15
D	VB	PE	0.12
E	VB	PE	0.15
F	AB	3-layer with woven reinforcement	Unknown
G	VB	3-layer: PE, PP (reinforcement and fleece)	0.20
H	VB	PP nonwoven + PP foil	Unknown
I	AB	PP fibre cloth with PP coating	0.20

2.2 Artificial Aging

All tests were performed on non-aged as well as aged samples, except peel resistance for membrane joint with membrane, which were only tested on non-aged samples. The artificial aging was performed by placing the samples for 84 days in a climate chamber at 70 °C and 90 % relative humidity followed by 84 days in a ventilated oven at 70 °C.

2.3 Peel Resistance

Peel resistance was tested on joints of two membranes and joints of membrane and aerated concrete (AAC). The tests were performed according to EN 12316-2:2013 that specifies how to test peel resistance of a joint between two pieces of a membrane. A sample was placed in a testing machine with the grips 200 mm apart. During testing the grips moved apart at a constant speed. The force used for peeling was recorded. The method was adjusted for the test with AAC because of the thickness of the AAC.

In addition, the speed of the tests was reduced from a separating speed for the grips from 100 ± 10 mm/min to 10 ± 1 mm/min. Samples used for membrane/AAC tests were approx. 14 cm wide instead of the standardised 50 mm, that were used for the membrane/membrane joints. The measured force was converted to the equivalent force for 50 mm samples. Figure 1 shows the principle of the tests as well as pictures from the testing. Five samples were tested for each material combination.

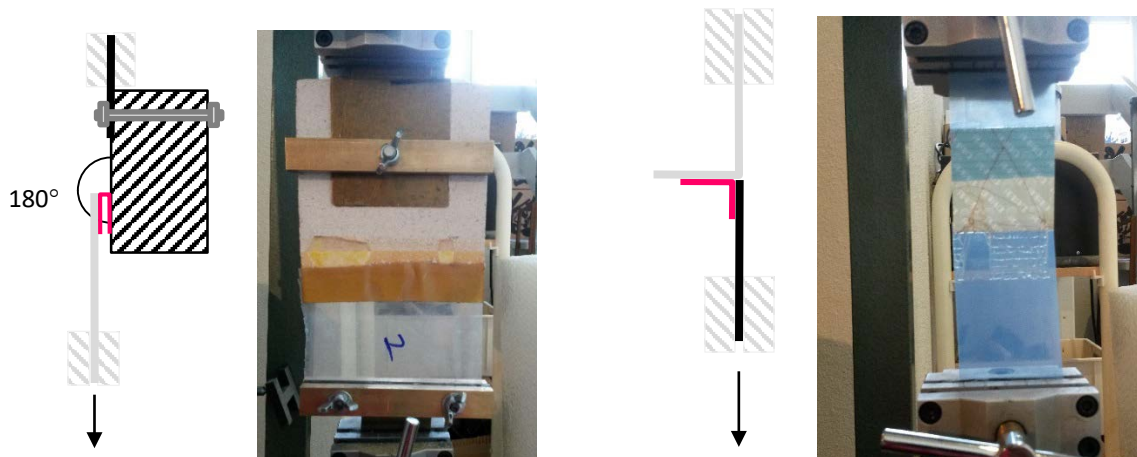


Figure 1. Test of peel resistance, sketch from the side and photo from the front. Left: Membrane taped to AAC. Right: Two pieces of membrane taped together.

2.4 Shear Resistance

Shear resistance was tested on aged and non-aged joints of membrane/membrane (see Figure 2) and according to EN 12317-2:2010. Similar to the peel test, the ends of the samples were placed in the grips of a testing machine with a constant separating speed and the shear strength was recorded. The separating speed was reduced from 100 ± 10 mm/min to 10 ± 1 mm/min.

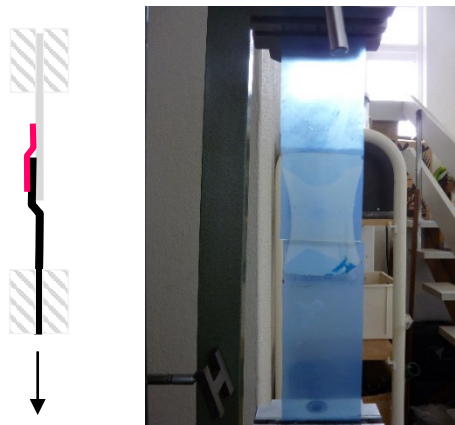


Figure 2. Test of shear resistance, sketch from the side and photo from the front.

2.5 Test of Airtightness

The test of airtightness was not a standard test but a test especially invented to simulate conditions in an older attic where it would be difficult to establish an airtight barrier. The aim was to test airtightness before and after artificial aging. The method is described in (Møller and Hansen, 2017). In short, it consisted of a wooden frame supplied with angled boards and a pipe in the middle. The inside of the frame was lined with the membrane to be tested and fixed to the frame with the system's tape. To secure airtightness around the pipe the system's collars were used and the pipe sealed. The frame was placed in a box leaving a small space between membrane and box, see Figure 3. It was ensured that the frame was airtight and so was the

connection between box and frame. Through a hole in the box a ventilator created a pressure difference between box and frame. The flow necessary to obtain pressurisation of 10, 22, 34, 46, 58, 70 and 82 Pa was recorded. The test was repeated three times and again three times with the same negative pressure differences. By linear regression, the results from the different pressure differences were combined to a single value for a pressurisation of 50 Pa. The test was inspired by the blower door test (EN/ISO 9972: 2015). After 164 days of artificial aging, the tests were repeated. One frame of each system was tested.



Figure 3. Test equipment for test of airtightness. Left: wooden frame with lining of membrane taped to the frame, pipe with collar in the middle. Right: wooden frame placed in box, a ventilator created a pressure difference between frame and box through a hole in the box (not visible on photo).

3 Results

To evaluate the tests results, these are compared to the requirements given by DUKO (2014) when manufacturers want to obtain a certification of their product. Therefore, a line, representing the requirements given by DUKO, has been added to the presentation of results.

3.1 Peel Tests

The DUKO requirements for non-aged joints of membrane/membrane and membrane/AAC is > 10N/50 mm. There are no requirements for aged joints. The results of the peel resistance tests are shown in Figure 4. All systems fulfilled the DUKO requirements. Except for system B, all membrane/ACC became stronger with aging. All non-aged membrane/membrane joints, except for system C, were more than 20 % stronger than non-aged membrane/ACC joints.

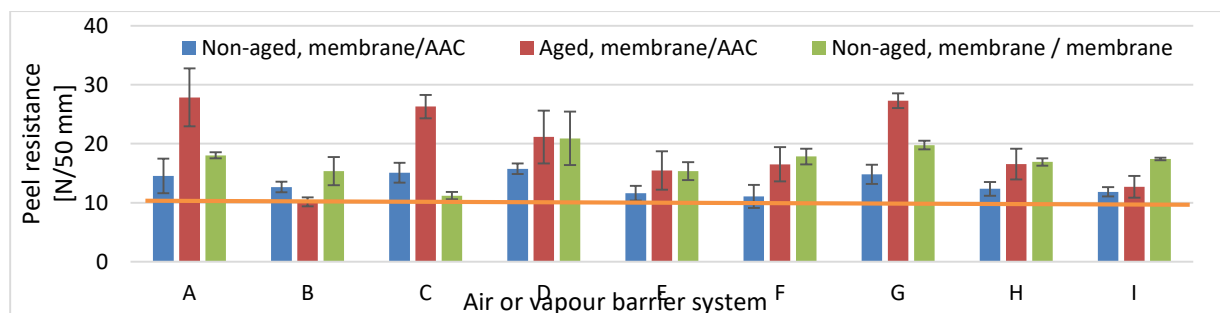


Figure 4. Result of test of peel resistance, average of five samples, with standard deviations. The orange line marks the DUKO requirements for non-aged joints, there are no requirements on aged joints.

Tapes consist of an adhesive and a carrier layer. As shown in Figure 5 there were different places where the adhesive could fail; either the bonding to AAC or to the carrier layer. Where the adhesive stayed showed where the best bonding took place.

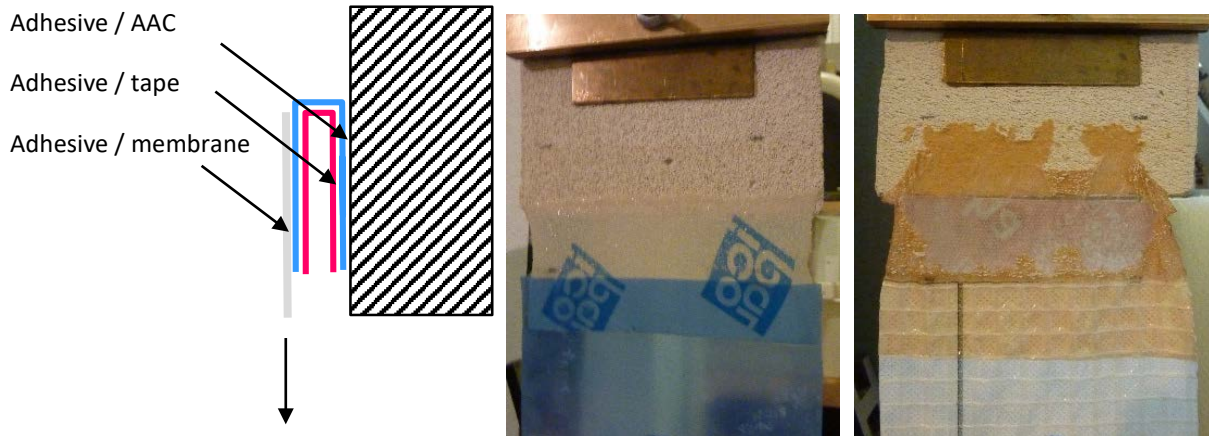


Figure 5. The failure of the adhesive could appear in different places, the sketch shows three possibilities in membrane/AAC connections. The photos show examples, Left: Failure between adhesive and AAC (very little adhesive left on AAC). Right: Failure between adhesive and tape as the adhesive left the carrier layer of the tape.

In some tests, the failure was not clearly between two layers, but parts of the adhesive would stay at the tape and other parts would be peeled of the tape or the failure layer was not the same in all tests of the same system. Consequently, some systems have two failure modes, which can be seen in Table 2, where the failure modes are presented.

Table 2. Point of failure in peel test. In no test did the membrane break.

	Point of failure	A	B	C	D	E	F	G	H	I
Non-aged, membrane/AAC	Adhesive/tape			x						
	Adhesive/AAC	x	x	x	x	x	x	x	x	x
	Adhesive/membrane									
Aged, membrane/AAC	Adhesive/tape	x	x			x	x	x	x	x
	Adhesive/AAC	x			x			x		
	Adhesive/membrane			x						
Non-aged, membrane/membrane	Adhesive/tape	x				x	x		x	x
	Adhesive/membrane	x	x	x	x			x	x	

3.2 Shear Tests

The results of the shear tests are shown in Figure 6, all systems fulfilled the DUKO requirements. The non-aged samples of system A did not come apart; the membrane, however, was stretched to more than the double of its length, without enhancing the force of the machine. In the rest of the systems, the adhesive did not stick to the tape. In the aged samples, the tape broke in system A and G, in the other systems the adhesive did not stick to the tape.

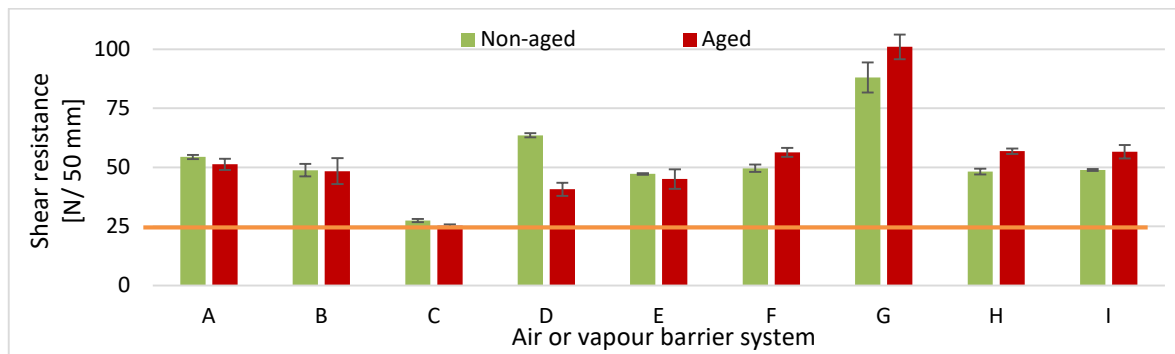


Figure 6. Shear strength, average of 5 samples with standard deviations. Orange line: DUKO requirements for non-aged and aged joints.

3.3 Airtightness

The results of the airtightness tests are shown in Figure 7. All systems needed higher air flow after aging, i.e. all systems were leakier after aging, typically 2-3 times more than before aging.

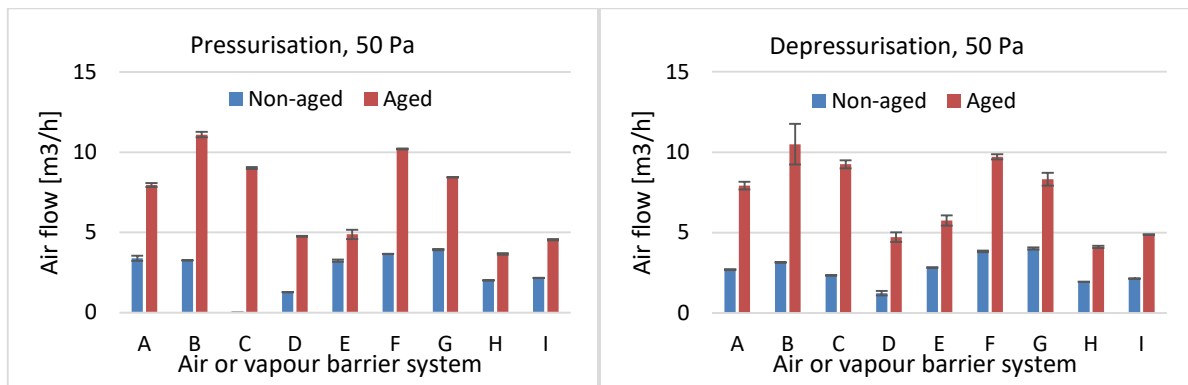


Figure 7. Test of airtightness of non-aged and aged systems, positive and negative pressure difference of 50 Pa. With standard deviations.

4 Discussion

Whether the aging method is the most relevant will not be discussed here, as this method has been discussed by Møller and Hansen (2017). Furthermore, there is no clear picture of which systems perform best, consequently, the discussion is limited to general results and the methods.

4.1 Testing of Peel and Shear Resistance

Although the testing of peel and shear resistance are two different tests, there are many similarities between the results, therefore, these are discussed collectively.

It was expected that peel and shear strength would decrease because of aging. However, the results contradict this; except for system B, peel strength on AAC was generally enhanced and shear strength on membrane/membrane was enhanced or only reduced by less than 10 % in all cases except system D where the shear strength was reduced by more than 1/3.

This is surprising, as practitioners have reported how some tapes, with time lose their ability to adhere to membranes, and from that generalised to all types of surfaces. Unfortunately, these

statements have not been verified systematically, and are only built on specific cases that experienced craftsmen have come across. Change of bonding may vary with aging and be surface/material dependent. Therefore, testing with a larger variety of surfaces seems needed.

However, it also raises the question whether the tests can predict the behaviour of the systems on site. The samples were made under ideal conditions: The joints were assembled on a plane horizontal support with a 2 kg roller under relatively clean laboratory conditions; this ensured the reproducibility of the test. Unfortunately, this may be in contradiction to conditions on site, where there should be a solid support, but the surface may not be plane and clean, the pressure used on the tape is not well defined. Hence, air leakage may not only be related to aging but to bad adhesion in the first place and consequently more sensible to aging than the tests foresee. It underlines the importance of correct workmanship, but questions the relevance of the tests.

In the peel tests of non-aged samples with AAC the adhesive was generally peeled of the AAC, while in the aged test the adhesive was more often peeled of the tape; apparently bonding to the AAC grew with aging. It is not clear why; maybe the heat decreased the viscosity of the adhesive, consequently, the adhesive could penetrate the pores of the AAC and thereby enhance the bonding. Maybe the outcome would have been differently if beech had been used instead of AAC, as prescribed in E DIN 4108-11:2016, the pores in beech are much finer than in AAC.

In the aged samples and most of the membrane/membrane joints, the failure occurred between the adhesive and the carrier layer of the tape. This means that it is not a problem to ensure bonding to membranes in shear tests or to AAC in general; the weak spot is in the tape itself, a better tape would be one where the adhesive bonds better to the carrier layer.

4.2 Testing of Airtightness

While the peel and shear tests are standardised, the test of airtightness was a new method, it is therefore relevant not only to evaluate the results but also the method itself.

The results of the airtightness tests were reproducible; each test was performed at least three times and the results were very close to each other; apparently, tests with pressure difference of up to 82 Pa did not influence the airtightness in the following test. The outcome of the test did also not depend on the operator, something that was also tested.

Contrary to the peel and shear tests, the testing of the airtightness showed a significant reduction caused by aging. Probably the uneven support made it impossible to make as perfect joints as in the standardised plane test samples; possibly tension in the joints caused leakage if these tensions opened the joints over time. The test was designed to simulate realistic conditions in a building and - contrary to the standardised peel and shear tests - the results agreed with statements from practitioners. The test might therefore be relevant. Unfortunately, the samples were not tightened to the same level of tightness level before testing, but only tightened to a level, where it was possible to obtain the needed pressure difference. In many cases additional tightening had to be done immediately before testing the non-aged samples. Consequently, the test only shows the influence of ageing of systems with a tightness above a certain level. Artificial aging seemed to be important, however, it is possible that the release of tension in the joints happened within relatively short time. The testing should probably have been performed more than 24 h after final tightening just as the peel and shear tests were. Other test methods that involve membranes, e.g. test of radon membranes, require a relaxation period of at least 40 hours after installation (Rasmussen and Cornelius, 2017).

DUKO (2014) has a method of testing airtightness that involves a mock-up of a wooden framework resembling a 12 m² wooden building. It is tested for airtightness twice with one week apart, but no artificial aging. By comparing the two tests methods, it might be possible to determine if artificial aging is important for the test.

5 Conclusion

The tested systems all fulfil the requirements for obtaining a DUKO certification on peel and shear resistance. In peel tests of aged samples on AAC and almost all shear tests, the weak layer was at the intersection between carrier layer of the tape and the adhesive, thus, improvement of the peel resistance should be an improvement of the tape itself not the bonding to AAC.

Surprisingly, the peel resistance increased with aging for taped joints to AAC, and shear resistance increased generally. Contrary to this, the test of airtightness showed significant losses in airtightness after aging performed in a wooden box. This raises the question whether the standardised tests of peel and shear resistance are performed under conditions that are too far from the conditions on site and therefore irrelevant. Additionally, it may be necessary to test on more surfaces than only membrane and ACC, e.g. wood.

The airtightness test was an attempt to find a different but relevant and reproducible test method. The method still needs to be improved, and compared with other test methods, but the result seemed to be reproducible and in concordance with experience from practice.

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