

WIND LOAD RESISTANCE TESTS OF HEAT-WELDED JOINTS BETWEEN ROOFING FELT AND SHEET METAL FLASHINGS

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ABSTRACT

The wind load resistance of joints between roofing felt and sheet metal has been measured in a wind uplift chamber. Both bituminous and polymeric roofing felts have been used. The sheet metal has been PVC-coated galvanised steel sheets and the bituminous roofing felts have been of both SBS and APP modified type. All the joints have been made with heat welding. The tests show that peeling is the dominating process in the failure of joints during wind load.

KEYWORDS

Low-slope roofing, flashing, membrane, APP, SBS, PVC, TPO, joints, single-ply, wind load

INTRODUCTION

On low-sloped roofs, a common type of roof cover in Sweden is the single-ply membrane. The normal method to make overlap-joints on these roofs is heat welding. The single-ply membrane is also often mechanically attached to the substrate and heat-welded to the details. Other methods of forming joints between the materials, like solvent welding or sealing with adhesives, are possible alternatives, but not used on the Swedish market for these types of joints and therefore not considered in this work either.

The formed joints can be tested in different ways, small samples can be cut out and tested with different methods or the whole roof area can be tested in a wind uplift chamber. A lot of these test methods are defined in standards but they all only cope with joints between sheets of the roofing membrane and not between the roofing material and for example metal sheets found in details on the roof.

The importance of research in to the adhesion between roofing felt and sheet metal flashings is borne out by the results from surveys. Some of the most common problems in membrane systems are to be found in flashings and lap or seam joints [1]. This is not surprising, since flashings are considered one of the most critical parts of the roof [2] or the major source of roof leaks [3].

Consequently, the strength of the joints between different components and their performance from different aspects is essential to the durability of the construction. When evaluating a roof, the focus must be on the whole field-manufactured roof systems including all details.

In earlier research [4], the strength of joints formed by heat welding between roofing membranes and sheet metal has been tested in small-scale tests. In this study, the joints are tested in large scale in a wind uplift chamber.

METHODS AND MATERIALS

General

The main idea in this study was to examine the strength of the joints between the membrane and the metal sheet in a large-scale test. To make comparisons to earlier research [4] easier the large-scale test was combined with a supplementary small-scale test.

Ordinary roofing membranes found on the Swedish market joined together with metal sheet were studied.

Materials

Four different roofing materials were tested consisting of two SBS modified bituminous membranes; one APP modified

bituminous membrane and one PVC membrane. The sheet metal was ordinary PVC-coated galvanised steel sheets except in combination with the APP membranes where the galvanised steel sheets were not the PVC-coated. The material properties are summarised in Table 1.

Table 1 - Material properties

	PVC1	SBS1	SBS2	APP1	APP2
Thickness	1,6	4,2	4,8	4,1	4,1
Reinforcement material	Polyester web	Non-woven Polyester	Non-woven Polyester	Non-woven Polyester	Non-woven Polyester + glass fibre web
Protection coating	-	Granulated slate	Granulated slate	-	-
Reverse side	-	-	Polyethylene film	Polyester film	-
Metal sheet	PVC-coated	PVC-coated	PVC-coated	PVC-coated	Bare
Coating thickness	180 μm	180 μm	180 μm	180 μm	-

METHODS

Large-scale

The large-scale test procedures were conducted according to NT Build 307 [5], which is a Nordic standard for large-scale test of roofing systems. The scope of the standard is to test the whole roof system including the membrane itself, the joints and the fasteners. The facility used for this test was situated at the Norwegian Building Research Institute in Trondheim. The test process contains both static and pulsating pressure that follows a program described in Table 3. The tests were carried out in a wind chamber as sketched in Figure 1. The chamber consists of the boxes; the upper and lower. A positive pressure is applied in the lower box and a negative pressure is applied in the upper box to simulate wind forces over the roof area. The boxes are separated by a roof deck on which the tested roof cover is mounted.

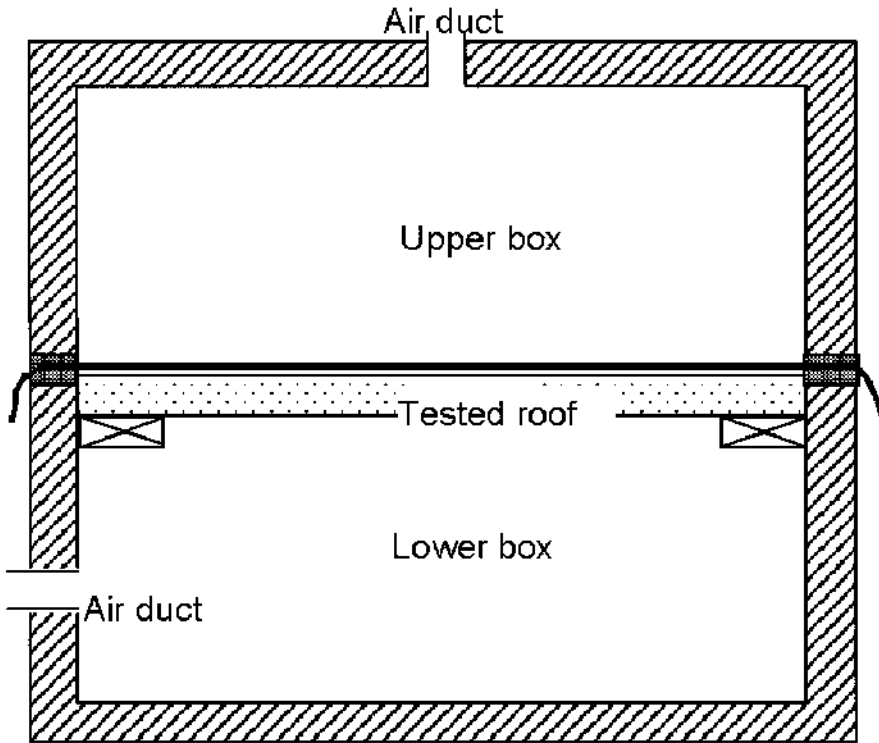


Figure 1. The wind-chamber at NBI.

Normally a tested roof cover area is made up of sheets attached to the substrate, often mechanically, and joined, most likely heat-welded, together to form a continuous layer.

In this project the emphasis is to the strength of the joint between the membrane and the metal sheet. Therefore are the tested roof areas differently made than usual. Metal sheets are mounted on the roof deck and the membranes are heat-welded to them. To insure that the weakest area is in the joint between the metal sheet and the membrane, no joints in the membrane itself are present and the fasteners are positioned in the metal sheet and are over-dimensioned. A sketch of the tested roof area can be seen in Figure 2. The dimensions of the roof deck are 2,45 x 2,45 m [6].

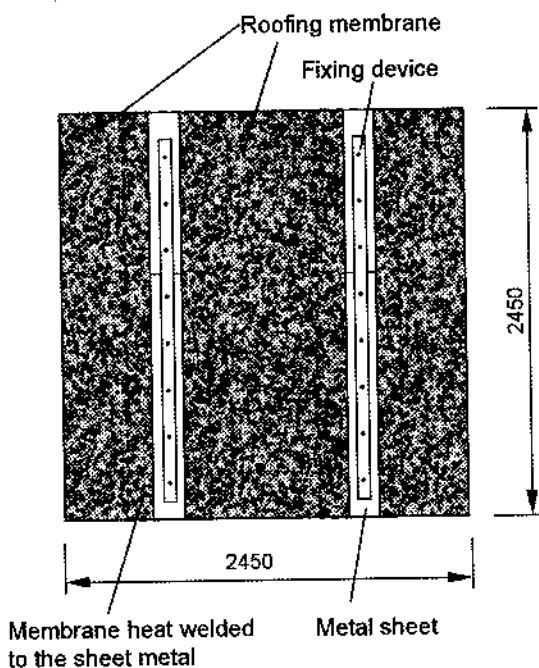


Figure 2. The test roof with roofing membrane and sheet metal.

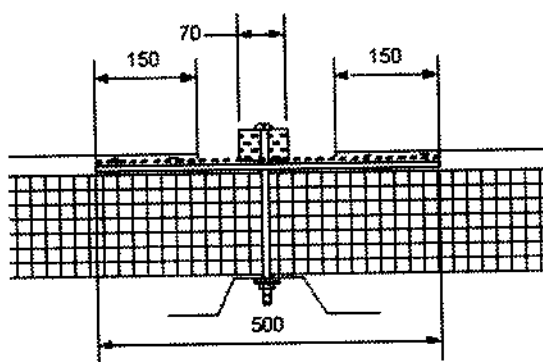


Figure 3. Detail of the joint between roofing membrane and sheet metal and the fixing device.

The metal sheets were nailed to a plywood sheet in a zigzag pattern with a 150 mm separation. The plywood was only present underneath the sheet metal and did not lie on top of the substrate, which was built up of 100 mm high density mineral fibre board over troughed sheet metal. The membranes were heat-welded to the metal sheet with a 150 mm overlap. All membranes were heat-welded with an open gas flame and in addition a roof was also made with SBS1 heat-welded with hot air from an encapsulated flame, see Table 2. The welding was performed by skilled workers.

To fix the roofing layer to the substrate, the sheet metal was anchored to the troughed sheet metal with screws through the mineral fibreboard.

With the roof area shaped like in Figure 2, two joints along the whole roof's length are subjected to the maximum wind force. The outer joints were not subjected to very high load but they were necessary to make the roof airtight and were used as a reference.

Table 2 - Materials and tests

Products	PVC1	SBS1	SBS2	APP1	APP2
Open flame heat welding	-	X	X	X	X
Hot air welding	X	-	X	-	-
Wind-chamber testing at +23°C	X	X	X	X	X
Small-scale test at +23 °C	X	X	X	X	X

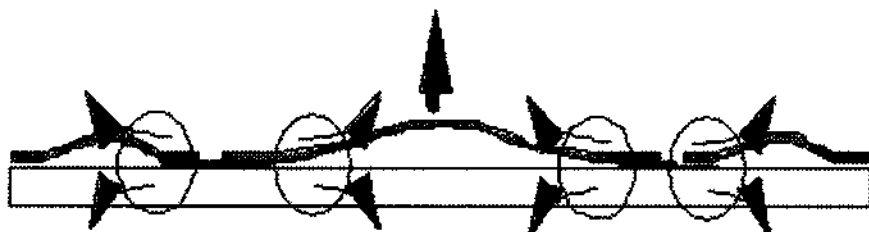


Figure 4. Section of test roof with arrows indicating strains induced by wind uplift.

Table 3 – The test procedure according to NT Build 307 [5]

Step no	1	2	3	4	5	6	7	8	9	10	11
Procedure B	Static load during 5 minutes										
kN / m ²	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0
followed by	Pulsating load during 20 minutes, 1 cycle per minute										
highest	0.7	1.4	2.1	2.8	3.5	4.2	4.9	5.5	6.9	8.3	9.7
lowest	0.3	0.6	0.9	1.2	1.5	1.8	2.2	2.5	3.1	3.7	4.3

Small-scale test

To verify the quality of the welding procedure samples were cut out of the tested roof area and used for small-scale tests. The samples were cut out in the undamaged area in the outer fields and included the joint with the metal sheet. The samples had a total length of 330 mm and a width of 50 mm. The welded joint had an overlap of 150 mm but the real length of the joints varied between 100 and 150 mm depending of the workmanship during the welding.

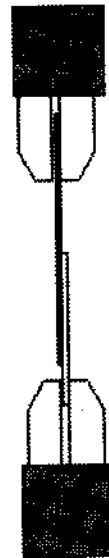


Figure 5. Short-term shear stress test holder.

To test the shear stress strength of the joints between the metal sheet and the roof covering, the specimens were fixed in a specimen holder, according to Figure 5, in the testing machine. The specimen holders were separated at a constant rate of 20 mm/min and thereby stretching the specimen until rupture, either in the membrane material or in the joint. The shear strength was calculated as the maximum force divided by the width of the sample.

All the short-term tests were carried out in room temperature in an Alwetron testing machine. In all cases, the force and extension during the tests were registered during testing 1.7 times each second. All tests were done with five parallel samples. The tests are summarised in Table 2.

RESULTS

Large-scale tests

All roof systems were tested in the wind chamber until failure of the joints. One system was even tested with two different welding techniques (SBS2-1 and SBS2-2); open flame respective hot air. In two of the systems (SBS1 and SBS2-1), the

strength was different in the two main joints. After the first joint had failed it was repaired and reinforced and then the process continued until the failure in the other joint was recorded. This was practised to ensure that the failure first recorded was not due to a local defect. All results are compiled in Figure 6.

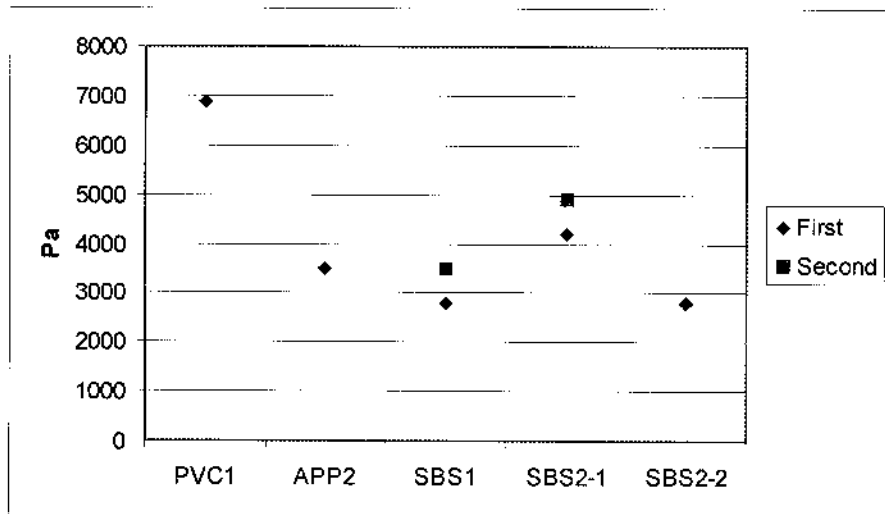


Figure 6. Wind chamber results. Failure strength in the joints between metal sheet and membrane.

As can be seen in Figure 6, the SBS2 joint made with hot air welding was somewhat weaker than the one made with open flame although still of the same magnitude as the other SBS material. After the failure of the joint the materials were torn apart and the weldings were examined. Very often, a pattern could be seen in the welding. The pattern in the joints is sketched in Figure 7. The cause of this pattern is uneven compression of the joint during welding. Where the pressure has been higher, the bonding between the materials was significantly better. During the welding process, the worker used his feet to compress the joint. Consequently, the pattern in the welding is the pattern of footprints. This shows the importance of a good and evenly applied pressure during the welding procedure. A roller with a sufficient weight should be the solution as earlier shown for joints between roofing plies [6].

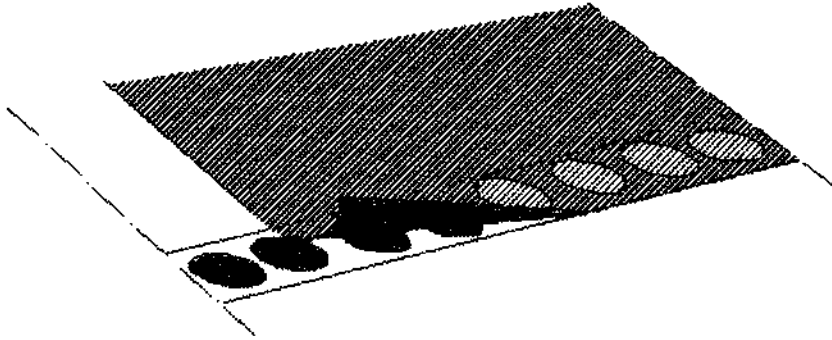


Figure 7. Footprint marks in the opened joint between the metal sheet flashing and the membrane.

Small-scale tests

In the small scale-tests, the samples were stretched until rupture in the membrane or disbonding of the materials. Only in the case of APP2 the rupture occurred in the membrane, in all other tests the membrane separated from the metal sheet. The measured strengths are compiled in Figure 8.

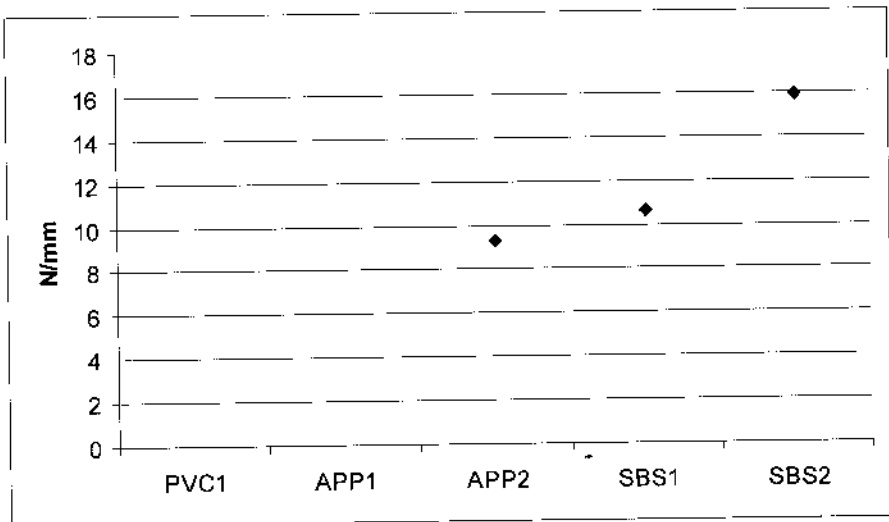


Figure 8. Shear stress strength measured in small-scale test.

DISCUSSION AND CONCLUSIONS

The dominating process in the failure of the joints in the large-scale wind box tests was peeling. Only a few marks of shearing could sometimes be seen.

According to the Swedish design regulations [8], the maximum dimension value of wind uplift can be calculated at about 3.4 kN/m². This is equal to a wind velocity of 43 m/s on a 10 m high building. Most tested roofs withstand values higher than this (Figure 6).

In the case of the small-scale test, where the failure of the joints was disbonding of the materials, the process had marks of peeling. When the samples were subjected to the force, the membrane was both elongated and the width was contracted. When the membrane contracted the bonding was torn apart. With the continuing contraction of the membrane the disbonding continued until the materials had separated. In the case of the APP2, the membrane was weaker than the joint, which should indicate a very strong joint.

When comparing the large-scale tests with the small-scale tests, the first obvious thing is that the strength differs a great deal between the tests. The significant lower strength of the large-scale test indicates that the process is not shearing. The contractions of the membrane present in the small-scale tests are not to be found in the large-scale tests; on the contrary, the membrane is stretched by the wind uplift. This means that the process that destroyed the joints in fact was a peeling force and not a shear force.

When the materials, during welding, were pressed together in an uneven way, the joint contained weak regions. It seems possible that the breakage by peeling was much influenced by these weak regions.

With a peeling force dominating the failure process, it is very important to minimise its potential by ensuring that the joint really covers the whole overlap and thereby not supporting the peeling with a start.

When welding with the open flame the PVC-coating on the metal sheet sometimes got discoloured or a cracked surface.

This degradation of the coating, which was not observed during the hot air welding, could seriously alter the service life of the metal sheet and should therefore be avoided.

ACKNOWLEDGEMENT

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