THE ASSESSMENT AND TESTING OF MEMBRANE ROOFINGS

Jack O. May
Chief Technical Officer, The Agrément Board, Hemel Hempstead, Herts, England

INTRODUCTION

The Agrément Board started its building product assessment role early in 1966, when new single-skin roof waterproofing systems appeared in the United Kingdom market. Some of these products were assessed and accepted by the Board, but their subsequent behavior in use has not justified their initial acceptance. These early products were based upon plasticised PVC or elastomeric materials fully bonded to the substrate with a solvent adhesive, with lap joints welded chemically or by the application of heat. Chief problems with these materials were as follows:

- Inadequate site workmanship – notably, improperly sealed joints (especially serious on ponded roofs).
- Insufficient adhesive bonding membrane to substrate, resulting in loss of roof covering by wind suction. (In one situation, only a 15% bond area was achieved.)
- Poor detailing at perforations and interruptions in the roof covering. In general, the details were used for traditional bitumen felt coverings. But the adhesive used did not have the same gap-filling properties as hot bitumen. These details were most inadequate on complex roofs rejected as unsuitable for conventional bituminous materials.
- Use of a temperature-sensitive adhesive in conjunction with a material that exhibited fairly high thermal shrinkage, resulting in the material pulling away from the upstands, etc.
- Mechanical damage from pedestrian traffic, other trades working on the roof or vandalism.. The materials were designated for use on roofs defined as of "limited access" – i.e. roofs subjected to maintenance traffic only. In practice, many such roofs, particularly those on communal buildings, received a much higher level of traffic – for example, regular impact of stones and bricks thrown onto single-story school roofs.

Some of these problems were aggravated by the trend which started at about the same time as the introduction of single skin roofings, toward lightweight structural decks. Chipboard, for example, is very moisture sensitive, and any leakage through the roof covering damaged the structural integrity of chipboard deck.

As a result of these experiences, the Board had now restricted the use of these materials in the following manner:

- Single-skin roofings are not to be used below a 2-degree slope, unless the joint is a double joint usually achieved by covering the normal overlap joint with a separate sealing tape.
- The roofs should be simple in construction, without excessive perforations or interruptions in the roof covering. In some instances, the size of the roof is limited.
- Roofs previously designated as "limited access" have been subdivided into various intensities of usage which can be related to building types, and roofing materials have been classified according to their resistance to mechanical damage.

Since the initial advent of new roof membrane materials, many different materials have been developed both in the United Kingdom and Europe. Because of the possible export potential of these materials, the European Union of Agrément (UEAtc) decided some four years ago to produce a standardised system of assessing these products, so that the Agrément Certificates issued in one country could be easily transferred to another.

The European Union of Agrément, comprising nine European countries, has not yet managed to agree on a document to publish, but earlier this year, they did decide to issue a provisional document so that the various countries could use standardised test procedures. Further discussions on the interpretation and limits for some of the tests will be necessary. The test methods described in this paper are used by the UEAtc.

PERFORMANCE TESTING OF MEMBRANE ROOFINGS

Membrane testing is complicated by the large number of variables in design, in materials used in association with the membrane, and in the varied usage of roofs.

The build-up of roofs can vary from a very simple system, comprising a structural deck with a waterproofing membrane only, to a complicated system involving vapor barriers, venting layers, separating layers, screeded layers, insulation, membrane, and a protective layer.

The roof may be dead flat, with stagnant water standing on the waterproofing for relatively long periods of time; it may have a moderate slope when stagnant water will only stand on the surface occasionally when the drainage system is blocked; or it may be pitched so that stagnant water never remains on the surface.

The waterproofing may be laid in contact with a timber, concrete or metal structural deck or be laid onto an insulation of mineral, vegetable or plastic material.

The membrane may be fully bonded, partially bonded, mechanically fixed or laid loose on its support. A protective layer may be applied to the waterproofing in the factory or on site. Site-applied protections can vary from a paint finish to the application of several inches of aggregate or of concrete slabs.

Roofs may be defined as (1) non-access roofs where the structure of the roof deck is insufficient to withstand the weight of a man without the use of crawler boards to spread the load, (2) limited access roofs, where the only envisage access is to maintenance traffic to effect repairs to the roof or to other parts of the building, (3) pedestrian access roofs, (4) vehicular acess roofs, and (5) roofs designed for special purposes, such as roof gardens.

Although for any particular membrane, the number of variables can be reduced, there is still a large number of possible combinations of waterproofing and other materials that have to be assessed. It is obviously impossible to test all of the possible variables, so for our own assessments, we select for each particular test the combinations likely to give the worst results. Or we carry out tests at the two extremes of the spectrum. For example, for our tests on wind uplift and mechanical damage, we usually test the material on concrete, fiberboard and expanded polystyrene supports.

The following are the main performance tests that are carried out on roof membranes:

1. Behavior in fire
2. Wind-uplift resistance
3. Watertightness
4. Resistance to thermal effects
5. Fatigue resistance
6. Resistance to mechanical damage
7. Site handling characteristics
8. Durability

1. BEHAVIOR IN FIRE

Fire requirements for roofing materials are laid down in National Standards and Regulations. In Europe, they contain limitations on surface spread of flame, fire penetration, and, in some cases, flammability. The fire rating for any particular waterproofing system depends on the waterproofing medium, the substrate on which it is laid (combustible or non-combustible) and the protection given to the waterproofing and roof slope.

2. WIND-UPLIFT RESISTANCE

Bonded or mechanically fixed roof membranes are subjected to almost continuous wind suction force. Either through direct pull-off force or peel force, wind suction can cause loss of adhesion between the system and the deck between the jointing tapes and the waterproofing material, or between layers of the waterproofing material. It can also delaminate composite materials. Most previous testing has involved simple pull-off tests (with maximum wind loads laid down in National Regulations as the criteria for acceptance). Conducted with relatively small samples, these tests yielded highly variable test results, which have not always related to experience in practice.

The present test method involves a relatively large test sample and a simulation of the suction forces exerted by the wind. In addition, a simple peel test is carried out, although at the present moment, we do not know how to interpret the results in terms of resistance to wind loading.

Test For Resistance To Pull-Off Under Suction

Apparatus: A box measuring 2 m x 1 m x 0.5 m depth consisting of a base and four sides designed to withstand a vacuum of 1000 da N/m^2 without deformation. In the two short ends of the box, viewing windows of transparent perspex are incorporated.

A lid that can be hermetically sealed to the box.

A connection from the box to equipment capable of applying progressive suction force.

Test Samples: A roofing sample measuring 2 x 1 m is bonded or fixed to a support (concrete, timber, thermal insulation, etc.) laid in the bottom of the box. If the support does not possess the weight and rigidity required to resist the suctions, it is fixed to the base of the box. The test is carried out with a longitudinal joint (2 m) between two support elements, the joint being vented through the box to the external atmosphere.

The roofing material is either fully bonded, partially bonded, or mechanically fixed to the support and the edges around the perimeter of the box sealed with a flashing.

When the test is performed on a fully bonded system, the roofing is fully bonded to the support except at the joint. A fold, 30-mm wide and 10-mm high, is made in the roofing material over the joint throughout its length by means of a shaped timber batten later removed.

When adhesives other than hot bitumen are used to bond the roofing, the samples should be allowed to stand for 7 days before testing.

Method: The box is attached to the source of vacuum and the following pulsating suctions are applied to the roof covering. The suctions should be applied to give as near as possible a 3 second pulse.

500 cycles from 0 to 100 da N/m^2
500 cycles from 0 to 200 da N/m^2
500 cycles from 0 to 300 da N/m^2
and so in in increments of 100 da N/m^2 up to 1000 da N/m^2.

Observations: The behavior of the roofing is observed at each stage through the perspex window, and the suction at which failure occurs is recorded. After the test, the roofing is examined for mode of failure, which is reported.

The following modes of failure are possible for bonded systems:

(a) delamination within the membrane itself
(b) failure at the membrane adhesive interface
(c) cohesive failure in adhesive layer
(d) failure at the adhesive-support interface
(e) cohesive failure within the support

The following modes of failure are possible for mechanically fixed systems:

(a) delamination within the membrane
(b) tearing of the membrane material at the point of fixation
(c) pull out of the mechanical fixing from the support

Test For Reistance To Peel

Apparatus: Tensile test machine (Instron).
Peel test frame

The apparatus consists of a peel test frame capable of maintaining a 90° peel angle throughout the peeling process.

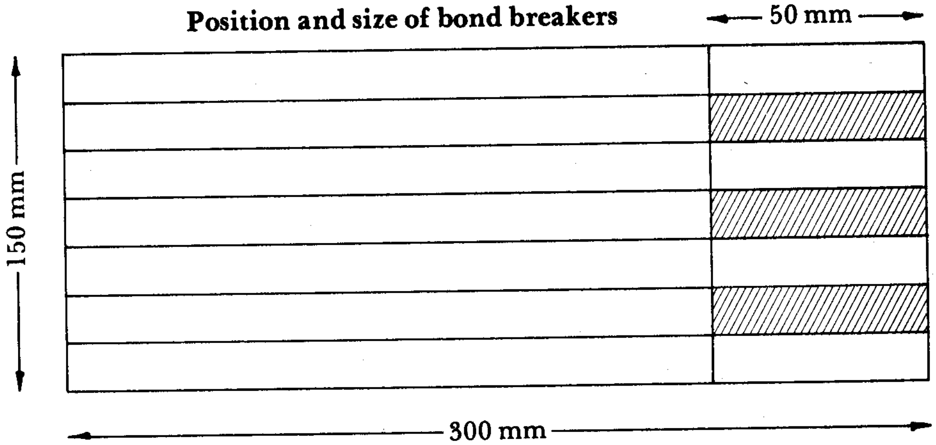
It is essentially a rigid steel frame mounted on the moving cross head of the tensile test machine. On this frame is located, by means of free-running bearings, a carriage onto which the specimen is mounted. The carriage freely runs along the axis of peel. By means of a wire-and-pulley arrangement, the motion of the cross-head of the tensile test machine is transferred to the carriage in the ratio 1:1. A counter weight is fitted to return the carriage to the start position and to maintain tension in the wire.

Test Samples: Specimens of built-up roofing are laid onto suitable rigid substrates of approximately 150 mm x 300 mm surface dimensions. A roofing sample the same size as the substrate is fully bonded to the substrate except at one end of the specimen for a distance of 50 mm. If the properties of the material are different in the length and width of the sheet, samples must be taken from both directions. To facilitate a satisfactory start to the peel, bond breakers, providing the 50 mm long break, are introduced. Cuts are made, down to the substrate along the length of the sample, to provide three peel strips 25 mm wide (see diagram).

Method: The test is carried out at 20°C. Three specimens are peeled one at a time, at a rate of 200 mm/min.

Observations: Maximum peel strength and mean peel strength are recorded. Type of failure is noted (i.e., adhesion, cohesion, delamination of roofing, etc.).

Position and size of bond breakers



3. WATERTIGHTNESS

The waterproofing material and the joints between sheets have to resist the passage of water into the substrate. The situation is worse for flat or nearly flat roofs, where water at relatively low pressure head may remain on the roof for long periods of time. The joints are critical where a single-layer waterproofing is used.

Test For Resistance to Water Pressure

Tests on Material

Apparatus: A pressure vessel with one side equipped for attaching a sample of the waterproofing material approximately 10 cm in diamater and a means of applying an 0.6 N/cm^2 pressure of water is required. A porous disc to support the underside of the sample and to prevent it from bursting is sometimes required.

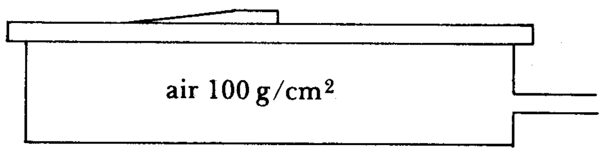
Test Samples: Three samples approximate 10 cm in diameter should be tested.

Method: The sample is fixed to the pressure vessel and sealed to ensure watertightness. The test pressure is applied for 24 hours.

Observations: No leakage of water should occur over the test period.

Test on Joints

Apparatus: Container with an edge lip-area 300 x 300 mm—provided with a clamping device and a compressed air supply.



Test Samples: Three samples with a useful area (sheet and joint) of 300 x 300 mm.

Method: The sample is fixed to the edges of the container and a seal is used to ensure watertightness. The joint is wetted with a soap solution. An air pressure of 100 g/cm^2 is introduced into the chamber and maintained for 30 minutes.

Observations: No bubbles should occur during the test.

The apparatus consists of a peel test frame capable of moving to maintain an angle of peel of 90° throughout the peeling process.

4. RESISTANCE TO THERMAL EFFECTS

The waterproofing system will be subjected to elevated temperatures and changes in temperature. The worst situation is a fully exposed, dark-colored waterproofing system, which will be subjected in Europe to a range of surface temperatures from - 20°C to + 80°C and rapid reversals of temperature of the order of 60°C.

The effects that can occur are:

(1) Thermal movements of the waterproofing material causing ruckling, ridging, blistering, etc.
(2) Loss of adhesion or delamination between the waterproofing and the support.
(3) Shrinkage of the waterproofing material due to loss of volatiles, plasticiser migration, stress relief etc., causing defects at joints, roof details, and loss of adhesion.
(4) Sliding of the waterproofing on sloping roofs.
(5) Fatigue movement of the support - dealt with separately.
(6) Aging of the material - dealt with separately.

Test For Resistance To Thermal Shock

Apparatus: Same used to test wind-uplift resistance, plus a means of heating the upper surface of the roofing with radiant heat.

Test Samples: Same used to test wind-uplift resistance.

Method: Heat upper surface of the mock-up with radiant heat to a temperature equivalent to 80°C. (Heating time should be approximately 30 minutes). Hold sample at maximum temperature for 1 hour. Then spray surface with mains water (temperature 15-20°C) for ten minutes. Repeat heating and cooling cycle daily at least 10 times. If there is evidence of continuing movement or deterioration after 10 cycles the cycling should be continued until equilibrium is reached. Finally, perform test for resistance to wind suction.

Observations: After each cycle, examine for signs of failure—loss of adhesion, movement of the material, failure of joints, blistering, etc. Very often, minor surface blisters occur in the first few cycles, but subsequently disappear. These are not considered significant unless accompanied by significant loss of adhesion.

There should be no significant change in the resistance to wind suction.

Test For Dimensional Stability

Test for unrestrained shrinkage (see Note 1)

Apparatus:—optical or mechanical device with a measuring range of more than 100 mm, suitable for measuring to an accuracy to within 0.05 mm.
—glass plate 95 x 95 x 6mm.
—dry ventilated oven, accuracy ±1°C.

Test Samples: 3 samples 100 x 100 mm.

Method: The samples are coated with talc on both faces, placed on a smooth support, and weighted down with glass plate. Dimensions are measured at three points crosswise and lengthwise. The mean value is calculated for each direction.

The samples are placed on aluminum foil inside the oven and conditioned at 80°C for 70 hours.

They are cooled for 24 hours on a smooth support, and the dimensions are measured as described previously.

The heating cycle is repeated until consecutive measurements do not differ by more than 0.1 mm.

Observations: The mean shrinkage is recorded as a percentage of the initial dimensions in each direction.

Note 1: With certain waterproofing materials containing plasticisers such as flexible PVC, shrinkage may occur by plasticiser migration into the adhesive or with non-adhesive systems, into the support, giving shrinkages greater than would be obtained by simply heating the material in the oven. When such a reaction is suspected, the test should be carried out with a layer of adhesive applied to the lower surface of the material or placed in contact in the oven with slabs of the envisaged substrates.

Test For Restrained Shrinkage

Apparatus:— optical or mechanical device with a measuring range of more than 200 mm, suitable for measuring to an accuracy to within 0.05 mm.
—dry ventilated oven, accuracy ±1°C.
—concrete slabs 300 x 300 mm.

Test Samples: Samples of roofing are bonded to the concrete slabs with a joint in the material running across the center of the slab. If from the unrestrained shrinkage measurement there is a significant difference in the shrinkage across and along the sheet material, samples with joints representing the two situations should be prepared. Three samples of each type are required.

The material is mechanically clamped to the concrete slabs to prevent movement at the edges parallel to the joint. Measuring marks are made either side of the joint, approximately 50 mm away from the joint edge. Three measuring points are made on each sample.

Method: Dimensions are measured, and the samples are placed inside the oven and conditioned at 80°C for 7 days. They are cooled for 24 hours and the dimensions are measured. The heating cycle is repeated until consecutive measurements do not differ by more than 0.1 mm.

Observations: Mean shrinkage is recorded as a percentage of the initial dimensions. Samples are visually examined for signs of stress at the joint or any loss of bond between the material and the substrate.

There should be no loss of bond or visible signs of stress at the joint.

Test For Resistance To Sliding (For Sloping Roofs)

Apparatus: Dry ventilated oven accuracy ±1°C.

Test Samples: The material is bonded to a concrete slab 300 x 300 mm.

Method: The sample is inclined at the maximum intended slope in an oven at 70°C for 7 days.

Observations: The sample is examined for creep or flow of the material. No movement should occur.

Note: The above test is not necessary if mechanical fixing at the top of the roofing sheets is provided.

5. RESISTANCE TO FATIGUE

Waterproofing will be subjected to fatigue due to thermal or moisture movement of the supporting material. In general, fatigue action due to thermal movement is more important than that due to moisture movements, which occur at a very much slower rate and at a lower frequency. The subject of fatigue of waterproof membranes is very complicated, and all the parameters are not yet fully understood. The following test is purely a means of comparing one material with another and relating the results to the performance of known materials. Fatigue resistance is important for fully bonded systems, less important for other systems.

Test For Resistance To Fatigue

Test on waterproofing material

Apparatus: The test apparatus consists of two platens provided with clamps to which two concrete slabs can be fixed, so that one of their edges is abutting, plus a means of opening and closing the joint between the two slabs at a controlled rate of amplitude.

Test Samples: Samples of the roofing material measuring 300 mm x 50 mm are bonded to the concrete slabs at their closed position with the middle of the long dimension positioned over the butt joint. Multilayer systems are built up as required.

Three samples of the new materials are tested and a further three after 28 days conditioning at 80°C.

Method: The joint between the two slabs is open and closed under the following conditions.

Rate of movement - 16 mm/hr.

Amplitutde - 2 mm.

Observations: The apparatus is stopped after every 50 cycles and the waterproofing examined for loss of adhesion, crazing, tearing, splitting or ruckling at the joint.

The requirement is no failure of new material after 500 cycles and no failure of aged material after 200 cycles.

6. RESISTANCE TO MECHANICAL DAMAGE

One of the main problems of some new forms of single-skin roofings has been the ease with which they have been perforated by people working or walking on the roof surface.

To overcome these problems, the materials are classified according to their resistance to static and dynamic loads as follows:

RESISTANCE TO PERFORATION	STATIC LOAD (L)	DYNAMIC LOAD (I)
Low	L_1	I_1
Moderately low	L_2	I_2
Normal	L_3	I_3
High	L_4	I_4

Buildings are similarly classified according to the level of stress expected. For "limited-access" roofs four different levels of stress, designated P_1 - P_4, are envisaged. These can generally be related to building or roof types.

DESIGNATION	STRESS LEVEL	BUILDING OR ROOF TYPE
P_1	Low	Architectural or sloping roofs where walking is difficult or impossible without special equipment.
P_2	Moderately low	Flat roofs of individual houses.
P_3	Normal	Flat roofs on building of multiple occupancy where maintenance of the building services from the roof is not envisaged.
P_4	High	Flat roofs on buildings where regular maintenance of the building services, lifts, ventilators etc., will take place from the roof.

The following minimum resistances to static and dynamic loads are recommended for the different building or roofing type designation.

	ROOF OR BUILDING DESIGNATION			
RESISTANCE TO PERFORATION GRADE	P_1	P_2	P_3	P_4
L I	L_1 I_1	L_2 I_2	L_3 I_3	L_4 I_4

Notes:

1. It may be possible to reduce the envisaged stress level in those buildings where access to the roof is strictly controlled, for example, where no permanent access to the roof is provided and equipment such as ladders have to be brought on site.
2. It may be possible to upgrade waterproofing materials by applying a suitable protection either overall or by providing protected walkways for regular traffic.
3. Roofs on single story buildings in certain locations may be subjected to vandalism by projectiles, large stones, etc., being thrown onto the roof. For these roofs, designation should not be less than P_3.

On access roofs for either pedestrians or vehicles, the waterproofing system is usually protected by rigid heavy protection (usually slabs), and mechanical damage to the waterproofing is not usually a problem.

Test For Resistance To Static Indentation

Test for resistance to static loads

Apparatus: A steel ball 10 mm in diameter. A means of applying constant loads of 5, 10 or 30 kg weight.

Test Samples: Samples of the roofing material are bonded or fixed to various substrates. In general, tests on at least two supports will be required. A rigid support i.e., concrete. A compressible support, i.e., plastic insulations.

Methods: The sample is loaded via the steel ball with a constant weight for 24 hours. The load is thereafter increased in stages until the waterproofing is perforated in 24 hours, each load applied to a different position on the test sample.

Observations: A record is made of the load that perforates the waterproofing.

Levels of acceptance:

- L_1 Perforated by the 5 kg load
- L_2 Not perforated at 10 kg but perforated at 10 kg
- L_3 Not perforated at 10 kg by perforated at 30 kg
- L_4 Not perforated at 30 kg

The results may differ for different substrates.

Test For Resistance To Dynamic Indentation

Apparatus: Baronnie hammer equipped with indentation blocks having 1, 2 or 5 ridges.

Test Samples: Samples of the roofing material are bonded or fixed to a concrete substrate.

Method: The sample is impacted using the Baronnie hammer with increasing levels of impact using the different indentation blocks. Impacts of 250 g, 500 g, and 1000 g mass.

Observations: Visual examination is made after each impact for perforation of the waterproofing.

Levels of acceptance:

- I_1 5 dihedra. No damage at 250 g mass.
- I_2 2 dihedra. No damage at 250 g mass.
- I_3 2 dihedra. No damage at 1000 g mass.
- I_4 1 dehedron. No damage at 1000 g mass.

7. Site Handling Characteristics

The waterproofing system must be capable of being installed over the range of climate conditions normal to external building construction work.

The following characteristics of the membrane and bonding agent are important in this respect:

(1) Resistance to tearing
(2) Flexibility at low temperature
(3) Ease of unrolling at low temperature

(4) Impact resistance at low temperature
(5) Ease of unrolling at high temperature
(6) Drying time of primers
(7) Setting time of adhesives
(8) Water sensitivity of primers and adhesives.

8. DURABILITY

It is necessary in any assessment of a membrane roofing to predict the product's service life. Generally, the European Union of Agrément require that the roofing system will give a minimum life of 10 years, with only normal maintenance, or with periodic renovation of a painted solar reflective treatment. Normal maintenace involves the removal of leaves, checking of the roof drainage and levelling and, if necessary, replacements of aggregate or mineral chippings. Waterproofing systems that are incapable of maintenance, repair or replacement, must preserve their qualities generally for the envisaged life of the building.

The assessment of durability involves consideration of the following factors:

(1) Changes produced in the material by the environmental factors. The changes may be caused by chemical or physical reactions.

ENVIRONMENTAL FACTORS	POSSIBLE EFFECTS
Heat	...Loss of extensibility Embrittlement Crazing
U/V Radiation	...Loss of extensibility Embrittlement Crazing Change of appearance
Water	...Erosion Hydrolysis Swelling Frost Damage
Oxygen (Ozone), Carbon Dioxide, Hydrogen Sulphide, Sulphur Dioxide, Sodium Chloride	...Chemical reactions
Bacteria, Lichens Fungi	...Rotting

(2) The compatibility of the parts of the total system. E.g.,

Plasticiser migration into the adhesive	...Loss of extensibility or embrittlement of material, softening of adhesive.

(3) The compatibility of the waterproofing system with other materials in the building construction with which it may be in direct contact or in contact via water borne solvation products. E.g.,

Lime washing from concrete	...Chemical attack

(4) The compatibility with materials that may be used on the roof surface. E.g.,
De-icing salts
Oils and petroleum products (on car park roofs)
Organic acids (on garden roofs)

In its procedure for assessing durability, the Agrément Board selects the factors likely to cause significant change in the materials, based upon the chemistry of the materials and the manner in which they are to be used. Materials are exposed to these factors whether at maximum service conditions or elevated conditions, if possible. We then follow the rate of change of a particular physical property, such as elongation against time. Whenever possible, results are compared with naturally exposed samples. Service life is predicted by interpolating from test data to field data.