NONDESTRUCTIVE METHODS FOR DETERMINING THE WATERPROOF INTEGRITY OF ROOF MEMBRANES AND SEAMS

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The determination of the waterproof integrity of entire roof membrane areas and total seam lengths during construction is accomplished by the use of a tracer gas. A low pressure method is used for checking large roof membrane areas. It is of particular value for membranes below coverings, such as ballast or insulation, that are installed over solid decks or existing roof membranes. A pressurized tracer gas is used to measure lap seam integrity, by employing a double seam, and for cap type seams. The width of bond, peel strength and shear strength are quantified for the entire length of the seam. This technique can also be adapted to standard single lap seams by the use of a jig to encapsulate discreet areas. Both methods are also used to provide nondestructive leak detection analysis after initial construction. Laboratory and field demonstrations are examined showing the method of performing these tests and describing the engineering analysis of the results.

The methods are particularly useful for single-ply membranes, both elastomeric and thermoplastic. There is also application for modified bituminous membranes and built-up roof membranes. The basis of both concepts is to identify the leaks directly compared to existing methods, which identify the effect on products that have been wetted by leak water.

KEYWORDS

Leak detection, nondestructive tests, "P" peel, quality control, tracer gas.

INTRODUCTION

Single-ply roof membranes by no means can be considered new technology. Single-ply membranes have been installed throughout the world for well over twenty years. Constructing roofing systems without leaks, preventing leaks from occurring, and locating and localizing leaks are major concerns in the roofing industry for all roofing systems. It has been postulated that single-ply membranes are leak prone because of faulty field-constructed seams of large sheets of plastic or rubber membranes.[1,2] The single line of defense, associated with single-ply systems has been considered to be an inherent weakness compared to multilayered, built-up roofs. From another perspective, should leaks occur in single-ply membranes, it is a problem, but not necessarily a failure. Leaks in single-ply membranes often occur soon after construction, and when located, can be repaired simply without damage to the membrane. Also, many of the materials within the single-ply roofing membrane systems are not deteriorated by short time exposures to water, such as plastic foam insulations, and coated metal or plastic fasteners. Too often leaks into water-sensitive, built-up roof systems are not noted in time to prevent failure of the system. Present methods of leak location vary from the simple and practical walking of a roof membrane by experienced mechanics to sophisticated testing equipment to survey the roof and plot the moisture content.

Roof systems that incorporate a top surface to protect the roof membrane make it difficult to locate leaks after construction. Stone ballast, concrete pavers and protected membrane assemblies are examples. Water resistant decks increase the complexity of locating leaks by diverting water laterally so the leak location in the interior has no relationship to the point of entry through the roof membrane. This is further complicated by roof system cross sections that include more than one barrier, such as vapor retarders, multilayers of insulation, and recently, the application of new roofing systems over existing roof systems. Many roof systems incorporate all of these impediments to locating leaks during and after construction making the timely location of leaks impractical. The result in many cases is that roofing systems are at some level of failure before leaks are identified, requiring removal of major portions of the roof system in order for it to perform acceptably.

The level of quality control incorporated into the manufacture of sheet membrane materials is good. Very seldom do the sheet materials arrive with breaches in the integrity of the roofing sheet. Large sheets, fabricated from narrow sheets by fusing or vulcanizing the sheet goods at the place of manufacture, also have a high level of quality. The integrity of the membrane can be compromised at the jobsite by damage to the membrane, or most often by discontinuities in the field seams of the sheet material.

Punctures in the roof membrane can be determined before a surfacing material is applied, but this requires visual observation of the entire roof membrane. Very often small tears or slits are not visible as the membrane material tends to self-seal visually, but cannot keep water from passing. Floodtesting a roof membrane, a technique used with solidly adhered membranes to monolithic decks (such as in plaza deck construction), is impractical because leak water would degrade the components of the roofing system. It is also impractical because the lateral displacement of water to the interior prevents positive location of the leak.

Field seams represent less than 2 percent of the area of an entire roofing membrane, but appear to be responsible for 98 percent of leaks. While the seams themselves are in obvious locations, for example, on 6m (20 foot) centers on a roof, breaks within the seam itself are not obvious. They are not visible even when viewed along the entire length or examined by mechanical probes. Often the seams appear to be well adhered along their entire length. Testing of the seams for strength and width of seam is accomplished by removing samples of the seams. This is a form of destructive testing. Samples are removed from the jobsite and taken to a laboratory for testing the seams in shear, or "T" peel. "T" peel is currently favored, purportedly being more representative of the quality of the seam.[3] The test information is then used to assess the quality of the entire seam. Therefore, if the tests prove to be below an accepted limit, the entire seam is considered to be below that limit. The converse is true should the test be passed. Because of the way field seams are made compared to the manufactured seams, spot testing does not predict the quality of the seam even a few feet away from the area tested. This is an expensive procedure and the test information often arrives after the roof is completed, making repair, if needed, impractical.[4]

The discussion to this point relates to quality control during or immediately after construction. Membrane systems that apparently pass these initial inspections can experience degradation of seams (or portions of the seams)[5] or subsequent punctures of the roofing membrane. Maintenance inspections done on a regular basis could locate leaks in roofing membranes that are exposed, or over roof structures that allow water to fall vertically through, such as a poured gypsum deck. However, the majority of the roofing systems do not lend themselves to easy location of roof leaks before large amounts of water are trapped within the roof cross sections.

Leak location, eventually determined by water entering the interior or by degradation of roofing products in the system, is unacceptable because it can prove to be too late to save the remainder of the products in the roofing system for future acceptable performance. There are survey systems to measure the effects of leakage into the system, primarily the insulation layer. Plots of the water level are made and then deductions can be made at the point of water entry. The roof membrane can be repaired, however, large portions of the roofing system that are wetted must be removed before such a repair is acceptable.

The purpose of this paper is to describe specific methods for the direct identification of leaks within the roofing sheets and through the seams of single-ply roof membranes. These techniques are based on the use of a pressurized air/tracer gas. They are essentially nondestructive in nature and can test 100 percent of the membrane area and seam area. This can be done as a quality control measure during construction, and after construction as a preventative maintenance program and for leak location.

LOW PRESSURE AIR/TRACER GAS LEAK DETECTION METHOD FOR SHEET MEMBRANES

In its simplest form an air/gas mixture is injected from the topside of the roof membrane to the underside, and detected by a gas analyzing probe that is methodically traversed over large areas of a roof membrane. The system is best suited for roofing systems for which it is inherently difficult to locate leaks. A double barrier system is required to incapsulate the air/gas system so pressure can be developed. Monolithic decks, vapor retarders or recovered roof systems are examples of barriers to leakage of the air/gas mixture to the underside. Roof membrane systems that are not totally adhered, such as ballasted or mechanically-attached systems, are best suited. Either of these conditions, or when both conditions exist, make it most difficult to determine punctures or openings within the roof membrane. As the complexity of determining leaks increases, the benefit of this leak detection system improves.

Laboratory Testing

Various sources to develop air pressure under the membrane were evaluated. They ranged from high pressure/low volume compressors to eventually relatively low pressure, that is, 76—127mm (3 to 5 inches) of water with high volume 1.4-2.4 m^3/s (3,000 to 5,000 CFM). The exit nozzles of the blowers were reduced to adapt to standard roof relief vent stacks left in place for future testing. Reducing the orifice resulted in an increase in velocity with the resultant decrease in volume of air. The pressure was varied to determine the distance the air could be propelled without disturbing the roof membrane. For ballasted systems which weigh 48 kg/m^2 (approximately 10 lb/ft^2), pressure of 76mm (3 inches) of water developed observable billowing, but did not disturb the top surface. This resulted in an effective diameter of approximately 15m (50 feet) with a head of water 25mm (1 inch). This was sufficient to expel the air through small openings, the sources of leaks. A tracer gas was introduced developing a concentration of approximately 100 ppm of air. This was easily detectable by a halogen sensor which read less than 10 ppm through various size and shape of openings at the perimeter. This determined the maximum diameter that could be tested. By using a pressure of 25mm (1 inch) of water, a hole or slit as small as 1.5—13mm (1/16 by ½ inch) could be located.

The gas sampling was determined by setting the parameters for this minimum size opening. The velocity of air/gas mixture exiting for a period of 10 seconds was 2.5 m/s (500 fpm). This provided a dilution of the air/gas mixture to the atmosphere outside the hole; for a 0.09m^2 (1 $foot^2$) area of 25mm (1 inch) depth, 10 to 1 reducing the 100 ppm to 10 ppm. These parameters were accepted as practical limits to allow economical canvassing of a roof.

Because the tracer gas was heavier than air, a collection device had to be used to lift the air/gas mixture. A halogen sensor with a small vacuum attachment built-in was selected. This device, when placed over the ballast area, approximately 25mm (1 inch) off the membrane, could detect the concentration of gas to 10 ppm when passed within 200mm (9 inches) of the test opening. A number of samplers based on a batch process were evaluated. Sampling by large plunger devices to collect the gas samples were ineffective, in that the dilution was increased to the point where the detector did not sense the presence of the air/gas mixture. Also, the height to lift the gas was excessive making it an inefficient gathering process. Large sheets of plastic film, approximately 6m x 6m (20 feet x 20 feet) were placed directly over a test area and left in place for 5-10 minutes. The sensor was placed through preplanned openings on 0.6m (2 foot) centers. This was of limited value in that it did provide isolation of the leak area, however, it was impractical due to the wind conditions.

A compromise approach was used where the final device was a shroud 1.2m x 3m (4 feet x 10 feet) of 1mm (45 mil) EPDM membrane that had four halogen sensors placed at the trailing edge along the 1.2m (4 foot) width. Walking at a rate of essentially 0.3m/s (1 ft./s.), the 3m (10 foot) shroud provided a dynamic covering of any discreet area for 10 seconds. Based on using a pressurized area of approximately 15m (50 feet) in diameter, a square of 12m x 12m (40 foot x 40 foot) area was canvassed. A 1.2m (4 foot) width with overlapping runs of 0.3m (1 foot) provided an effective 1m (3 foot) width coverage per run. At one minute per run the entire area was covered in 13 passes, or 13 minutes. This 147m² (1,600 foot²) area was covered at a rate of less than one minute per 10m² (100 feet²).

Field Evaluation

An original protected membrane assembly over a structural metal deck was covered with a 1mm (45 mil) non-reinforced EPDM membrane layed directly over the insulation; then the stone ballast replaced above the new membrane. This cross section provided a barrier on the underside of the new membrane which was also not viewable because of the ballast on the topside. A 100mm (4 inch) diameter roof vent was flashed into the roof membrane. An electrically driven air blower with a capacity of 1.4m³/s (3,000 CFM) was attached through a PVC pipe adaptor. The rate of flow and pressure of the air and gas was measured at the points of inlet (Figure 1) and outlet (Figure 2). The air pressure was regulated with a Variac (potentiometer) to 75mm (3 inches) of water. This was enough to billow the membrane by lifting 58 kg m² (10/lb/ft²) of ballast. This produced an air flow of 1m³/s (2,000 CFM). An acceptable pressure, 25mm (1 inch) of water, was developed at an approximate 15m (50 foot) diameter. A test probe at the perimeter measured the pressure and air velocity through a small hole. The hole was an "L" shaped slit with each leg approximately 12mm (1/2 inch). The effective minimum pressure was determined to be approximately 25mm (1 inch) of water with an air velocity through this hole size of 0.4m/s (500 ft/hr). The tracer gas was introduced at the source to a concentration of 100 ppm. This was approximately a rate of 0.02m/s (30 ft/hr). This ratio was selected on the basis of a dilution of 10 to 1 outside the membrane where gas sampling would be made. This developed a gas concentration equivalent to 10 ppm. A probe sensitive to halogenated gases was used to sense the air/gas mixture. The sensor is capable of reading 3 ppm.

With the air pressure and concentration set, a square area of approximately 12m x 12m (40 feet x 40 feet²) was encompassed within the 17m (50 foot) diameter to traverse the roofing membrane for determination of leaks. The sampling device was a shroud of EPDM membrane, 1.2m (4 feet) wide and 3m (10 feet) long (Figure 3). The length could be varied, which in turn would vary the time that any particular area would be covered. Moving at a rate of approximately 0.3m/s (1 ft/s), the shroud covered a discreet area of roof membrane for 10 seconds. This allowed the gas concentration to increase to the point where the probe would sense it.

Four probes were set across the trailing edge of the shroud 0.3m (1 foot) apart, providing an effective width of 1.2m (4 feet). The underside of the probes were protected from damage by a metal screen as they passed over the ballasted surface. These probes contained an interior fan producing a vacuum to lift the air/gas mixture. The effect of wind was accounted for by selecting a direction of movement that would be in direct line with the wind. The entire area was traversed approximately one minute per 40 foot run for 13 such runs with overlaps of 0.3m (1 foot). The 147m² (1,600 foot²) area was traversed in 13 minutes (Figure 4).

Various patterns were considered. The ideal situation was to follow the centerline with respect to the air entry point and move toward the outside periphery, thereby allowing the gas concentrations beneath the membrane to increase. Using a plastic line marked in 1m (3 foot) increments laid at each end of the runs, into and away from the wind, allowed for simple alignment to ensure the entire area was covered. As the system was being set up, obvious points of potential leakage were checked while the gas concentration was increasing and dispersing. These were flashings at the perimeter and protrusions. If the test was being done after leaks had been reported, the initial test areas would be in areas near or centered where the leaks had been reported.

Once leaks are located, the areas immediately surrounding the leaks should be investigated to determine what, if any, damage was caused by the movement of water laterally beneath the roof system. These areas should be repaired or replaced, as resealing the membrane of a system in which the underside precludes drying to the underside would not allow the water to escape. This would cause subsequent damage to the substrate materials such as, insulation, fasteners and deck.

HIGH PRESSURE AIR/GAS MIXTURE DETERMINING SEAM INTEGRITY

Thermoplastic seams sealed by solvents, or most often by heat fusion, and thermoset membranes sealed with adhesives or tapes, have been the site of leakage in single-ply membranes. Basically they have been points of leakage rather than lines of leakage because generally the seams are acceptable, particularly at the time of construction. The seams can have small intermittent points that are not sealed. Unfortunately, these points of discontinuity are not readily observable. Over time certain seam systems have degraded due to the exposure of moisture, or stress such as caused by wind action.[6,7]

Both strength of the seam and width of the seam must be known to determine the integrity. Even though the membrane is loaded in shear under actual field applications, the "T" peel test has been a better gauge of the quality of a seam. While the "T" peel test may be a good gauge of the integrity of the seam, it is only a measure of the portion of the seam tested and does not necessarily reflect the quality of the seam further down the line, or of adjacent seams. The "T" peel test configuration is duplicated on the job for the entire length of the seam by the use of entrapped high pressure air/gas mixture. This incorporates the need for a double seam, or, on existing roofs where only a single seam exists, the use of a mechanical jig to encapsulate an air/gas mixture in a discreet area of approximately 25mm (1 inch) width by 0.3m (1 foot) long in a series of such areas for an approximate length of 2m (6 feet). These methods measure both the width of the seam and the strength of the seam.

Laboratory Testing with Double Seams

A double seam can be developed by placing a 25mm (1 inch) wide breaker strip approximately 75mm (3 inches) inboard from an overlapped seam and adhering approximately 25mm (1 inch) width on the inboard side. This provides a continuous unseamed entrapped area approximately 25mm (1 inch) wide. When adhesives are used, a breaker strip of foil backed tape can be adhered to one side before the seam is made. When tape is used, the backing paper can be perforated to remove all but 1mm (1 inch) width on a 175mm (5 inch) wide tape, such that the bonded area would be 75mm (3 inches) on the exposed side and 25mm (1 inch) to the interior side.

The air/gas mixture is introduced through the use of a 6mm (1/4 inch) diameter copper probe. This probe is passed into the void between the two bonded areas along the seam. Air pressure is introduced through a hand pump or through a compressor. The pressure introduced is regulated with a relief valve to limit the maximum pressure introduced (Figures 5 and 6). The membrane between the adhered areas will expand to the size of a bicycle tire and form a configuration which is basically cylindrical. The width of the seam can then be noted and traced on the topside by the use of a marker, so a minimum acceptable width can be determined.

The pressure is preset so the peel strength can be determined. The pressure can be set to equate to a peel strength which is 80 percent of the minimum acceptable strength. The strength will vary with respect to the type of adhesive, the age of the seam from green to cured condition and the temperature. The entire length of the seam can be measured, for example, a 30m (100 foot) length. While the seam is inflated a tracer gas detector device is used to check the entire length to determine if leaks have occurred. After the test, the seam will deflate and the small probe hole can be patched. An adaption would be to utilize a tire valve which is left permanently in the system for checking the seams at a later date.[7]

Laboratory Testing with Single Seams

Attempts were made to incapsulate discreet areas on top of single adhered laps with a tab on the underside used to insert fasteners for mechanically-attached systems. A rectangular metal frame, approximately 100mm (4 inch) wide by 0.3m (1 foot) long, was placed on the topside and held in place by standing on it. The air pressure was applied through the membrane within the frame, however, the air leaked out before the pressure required to test the seam was developed. Subsequently, a bladder-type probe was developed and inserted below to act like an innertube within a tire. This allowed control of the air pressure by using a three-sided frame above, held in place by standing on it. Favorable results were obtained using this technique.

Various probes (Figure 7) were used ranging from 0.3m (1 foot) in length to 1m (3 feet) in length with a variable opening allowing a 0.3m (1 foot) long bladder to be exposed. This allowed the test probe to be moved 1m (3 feet) away from the opening in the membrane. Once the seams were pressurized, the halogen detector was passed along the seams to locate small leaks not visibly or audibly discernable.

Types of Seams That Can Be Tested

Figure 8 illustrates various seam configurations. There are some standard configurations in roof systems built today in which the probe system would perform, such as the double lap to enclose mechanical attachment devices where the basic concept of the double seam already exists (see configuration 5, Figure 8). There are seams where this technique would not work in its present configuration, but adaptations of the bladder concept would allow sections to be measured. Seams, such as configuration 1, Figure 8, could be measured in shear. To fully utilize the concept, double seams (configuration 7) should be incorporated in new construction. Using this technique serves as quality control during construction and immediately after construction (periodic checking at seams and checking seams should leaks occur).

Relationship of Pressure to "T" Peel

Thermoplastic and thermoset materials were seamed using a double seam with 25mm (1 inch) space encapsulated between the bonded areas. These were pressurized with an air/gas mixture to a preselected pressure. The width of the seams was noted and the variations marked. The pressure was increased until failure occurred. The width of the expanded area was measured at the time the seam began to fail, and correlated with the pressure at which it failed. With these two variables, the tensile force within the membrane was calculated. This relates directly to the "T" peel forces.

Samples of areas that did not fail in these test lengths, which ranged 0.6m (2ft) to 3m (10 ft) long, were cut into 25mm (1 inch) width sections and tested by using a spring scale to measure the peel strength. The peel strength measured using the spring scale compared well with the calculated values from the pressurized, or "P" peel, values. In addition, they also compared favorably with similar values reported by others, and compared to manufacturer's literature. Comparable results were found for reinforced thermoplastic at 3.5 - 5 k N/m (20-30 lb f/in) and non-reinforced thermoset materials at 0.5 - 2k N/m (3-12 lb f/in).

This method using air pressure for peel testing has been coined "P" peel. The conventional equations for measuring the stress in the walls of cylindrical vessels is used to measure the "T" peel.[8] Shear strength can be determined using the same mathematical relationships. The derivation for cylindrical shapes or portions of a hemisphere is shown in Figure 9. The equation is applicable to reinforced and non-reinforced membranes which tend to have different profiles.

Tracer Gas Selection

The tracer gas used for the testing was chlorofluorocarbon #12 used in the refrigeration industry. Fully recognizing that eventually chlorofluorocarbons (CFC) will not be available, the selection of an equally effective gas is to be considered. The present gas is one which is easily sensed in small quantities, less than 10 ppm by standard halogen detectors. These are portable in nature and easily adaptable to this test method. Also, it is a gas at room temperature, noncombustible, nontoxic, odorless and heavier than air.

Basically the cost is acceptable, however, the cost is increasing as steps are taken to limit the use of CFCs. A gas of similar properties can be used, such as that used in propellents in spray can dispensers, other halogenated gases and hydrochlorofluorocarbons (HCFCs).

Field Evaluation of Double Seams

The field evaluation was done by fabricating double seams on four separate roofs. In all cases, the roofing membrane was a 1mm (45 mil) EPDM sheet with the laps adhered with adhesive. The roofs were ballasted, but the ballast was held back from the seam areas until the testing was performed, repairs made, and the final caulk applied. The roof area totaled 4,000m (40,000 feet^2) with a total seam length of 700m (2,100 feet). Limited success was obtained on the first three roofs totaling 3,000m^2 (30,000 feet^2), as the breaker tape tended to reattach due to solvents in the adhesive. On the fourth roof, totaling 1000m^2 (10,000 feet^2) with a seam length of 230m (700 feet), the system proved to be totally successful.

The adhesive seams were made following the normal procedure recommended by the manufacturer, with the exception that the overlap was extended from a minimum of 75mm (3 inches) to 150mm (6 inches). After the surfaces were prepared and the adhesive applied to the membrane, a 25mm (1 inch) wide paper tape was applied separating the full width into an outer width of 75mm (3 inches) and an inner width of 50mm (2 inches), and a void in the center of 75mm (1 inch). On the last roof, two layers of tape were applied to ensure the tape would not seal the void area.

In all cases the seams were tested the day after they were prepared. The surface temperature of the membrane was approximately 45°C (115°F). Because of the high temperature and the "green" strength of the adhesive lap, a "T" peel strength of 500 N/m (3 lbs/in) would be the strength of a well prepared lap. A pressure of 35 kPa (5 psi) was induced in the void through the use of a hand pump inducing the "T" peel loading. The entire length of each seam, which ranged from 20m (50 feet) to 30m (70 feet), inflated in approximately 10 seconds when the entire seam was satisfactory. Where there was a leak, either to the inside or to the outside, the void refused to inflate. The seam was shortened by stepping on the seam within a few feet of the point of air entry. The void space would inflate, and by extending the length of this inflated seam area, the area of leakage was noted as soon as the seam length was extended past it. The areas of openings through the outer seam were marked, and the width of the seams marked where the specifications were not met (less than 75mm or 3 inch width).

The time to prepare each seam for testing was one to two minutes, and to perform the test approximately one minute. The 13 individual seams on this roof were tested in one-half hour. Thirteen leaks, or incipient leaks, were noted in these seams which had been visually checked beforehand and rated as acceptable.

The areas of probe insertion were repaired using compatible materials. At the same time, the areas marked for repair were corrected. The double seams remain in place for future testing in a preventative maintenance program, or in the event leaks should occur.

ADVANTAGES

Entire roof systems, including the field of the membrane, seams and projections, can be tested during construction allowing early identification of areas needing repair in a timely fashion. It eliminates the need to base the quality of the roof system on spot evaluation.

It provides a mechanism for repeated inspections on a periodic basis using the same test probe areas. The initial probing is essentially nondestructive. For testing the field of the membrane, vents are left in place or vents which are in place are modified to accept the air compressor. Small test probe areas to calibrate the system are easily patched with compatible materials.

The testing of seams requires minimum openings, particularly if they are double seamed. After the testing, small patches are applied, or check valves installed and left in place.

Should leaks occur, they can be identified by testing the general area of the roof where the problems were noted, or by continuing the testing over the entire membrane area and all the seams. When leaks are noted the area immediately adjacent to the leak area can then be evaluated to determine if there has been consequential damages to the insulation, fasteners, etc. These methods provide direct observation of the leak rather than relying on deduction as required by typical moisture surveys.

The use of a double seam provides another line of defense for a roofing system should the exterior seam leak. When a test is run and pressurization cannot be maintained, whether it is an inside test lap or the exterior waterproofing lap that has failed, it can be determined by passing the halogen detector along the seam line. Also, the entire seam can be shortened by stepping on, or putting weight on, the seam line to shorten the seam to the point where pressurization can be maintained. This provides the mechanism for locating the leak at the interior seam. The cost to double seam a roofing membrane system, while quantifiable, is nearly inconsequential compared to the damages incurred by a number of small leaks within many miles of seam length.

Because many roofing systems have double barriers, with the high usage of recover systems with double barriers (the old and the new membrane), the new roof system can be saved from failure by early detection of leaks. Water can go undetected for an indefinite length of time between the membranes so the interior of the roofing system is subjected to subsequent undiscovered destruction.

It provides a tool for contractors, manufacturers, specifiers, consultants and owners at a reasonable cost to ensure a roof is constructed properly and remains watertight.[9] It provides direct location of leaks in a timely fashion to preserve the roof membrane assembly.

LIMITATIONS

The system for testing seams is not compatible with all roofing systems. However, it is compatible with most, and in particular those in which leak detection is the most difficult. It is not readily adaptable to testing of seams that are single lap without a protruding tab on the underside. This is most typical for ballasted roofing systems. With the mechanically attached tab, the probe approach will perform. However, because the membrane is visible, no ballast on the topside, leaks can be found by keen observation. For locating leaks in the field of the roof, the membrane must not be bonded to the substrate and there must be a barrier allowing the build-up of pressure within the roofing cross section. This makes it particularly adaptable to double membrane systems.

Some of the techniques discussed may be covered by patents so implementation may have to be accomplished under specific guidelines.

Where relief vents are part of roofing systems, some of them can be adapted to the insertion of the air pressuring device, but the others must be sealed during the testing to allow the pressure to build up.

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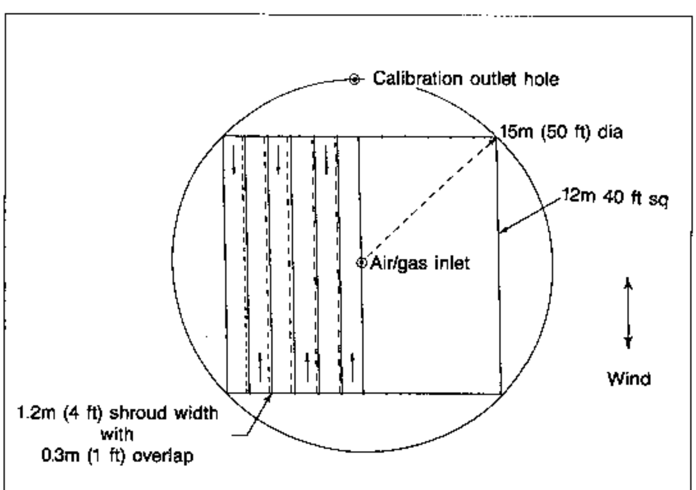

Figure 1 Typical pattern for canvassing for membrane leaks with shroud gas sampler.

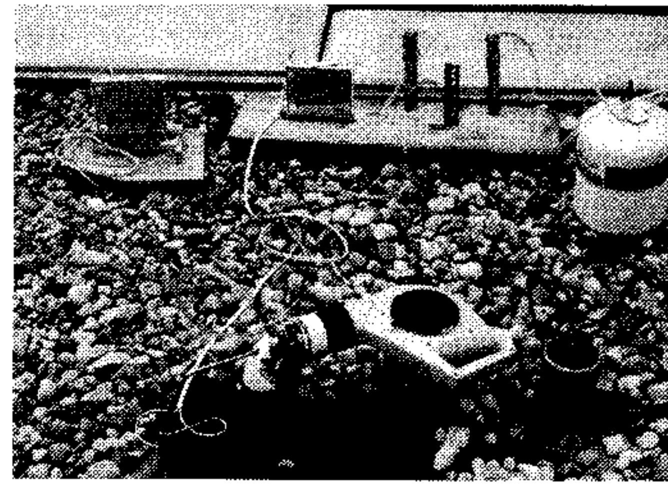

Figure 2 Air/gas mixture entry point showing regulated blower and instrumentation for measuring pressure and velocity of air and gas.

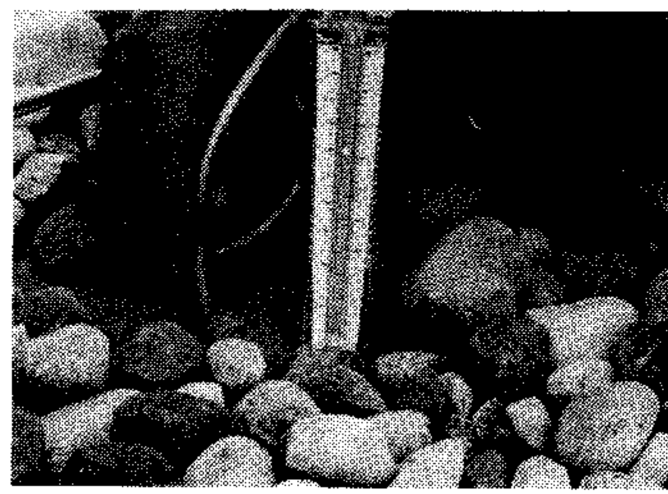

Figure 3 Portable measurement device for measuring pressure and velocity of air/gas mixture as it exits from a test hole that approximates the typical leak point.

Figure 4 View of the shroud used to traverse the membrane surface providing a cover time of approximately 10 seconds. This allows for the air/gas concentration to increase, and detected by a series of sensing probes.

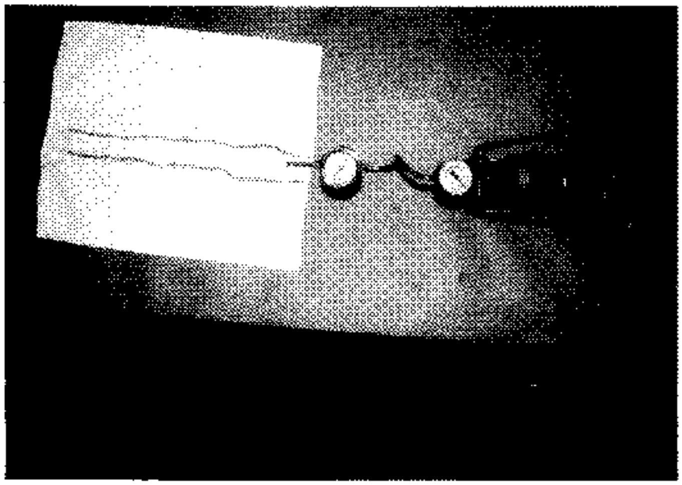

Figure 5 *Test apparatus for measuring pressure and width of seams for thermoset and thermoplastic materials. Double seam mechanism used with pressure developed by portable pump. Note varying widths of seams showing faulty seam areas.*

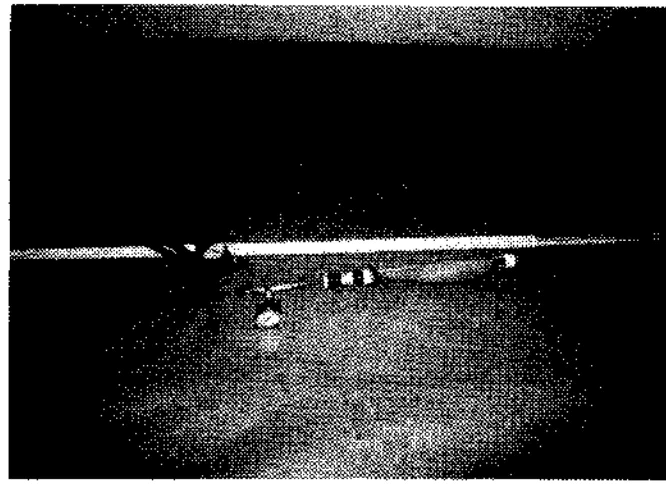

Figure 7 *View of two types of probes used with single bonded seams including a tab for mechanical attachment on the underside. Short probe shows inflated bladder. Long probe incorporates bladder with extension to incompass longer seam lengths.*

Figure 6 *A double seamed elastomeric membrane pressurized with portable pump. Note failure at top center of sample and variation in seam width.*

Typical Seam Configuration	Test Procedure	
	Double Seam	Interior Bladder
1 Lap	No	No
2 Mechanically fastened tab	No	Yes
3 Inner Caulk bead	No	Yes
4 Extra overlap	No	Yes
5 Mechanically fastened with cap	Yes	Yes
6 Lap repaired with lap	Yes	Yes
7 Double seamed lap	Yes	yes

Figure 8 *Relationship of seam type to test method (double seam and single seam).*

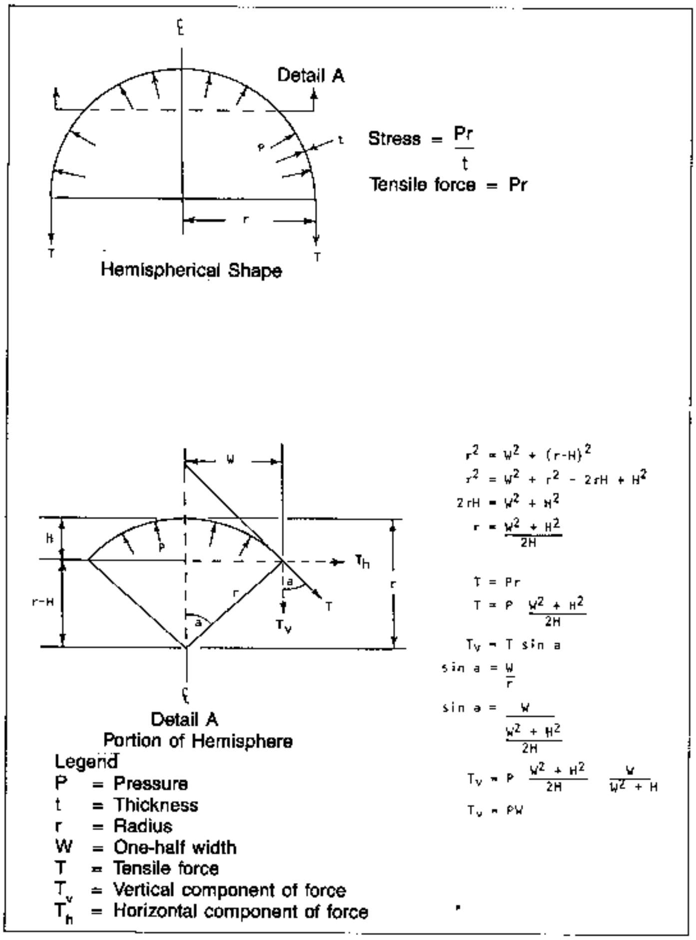

Figure 9 *Tensile force relationship to pressure and width of shape.*