THE EFFECT OF ROOF TRAFFIC AND MOISTURE ON THERMAL ROOF INSULATIONS

Executive Summary

Recent studies of low-slope roofs in Europe suggest roofing systems constructed using mineral fiber insulation (also known as mineral wool or rock wool) and flexible single-ply roofing membranes may experience significant degradation and eventual failure when subjected to water vapor intrusion, especially when combined with roof traffic. This study, commissioned by the Polyisocyanurate Insulation Manufacturers Association (PIMA), extends previous research to North American roof installations of similar mineral fiber insulations and single-ply membranes. The results of this study validate the results of the European studies, suggesting that roof traffic and/or water vapor may reduce the strength of mineral fiber insulation to an extent that may lead to roof system deterioration and failure. In fact, using the same evaluation scale as previous European research, the roofs examined in this study with mineral fiber insulation would be classified as "not suitable for roof traffic." As a result, the study suggests that roof problems and failures similar to previous European experience are likely to be repeated in North American roofing assemblies whenever mineral fiber insulation is used in combination with single ply membranes in high-moisture and/or high-traffic situations.

Introduction

In both Europe and North America, single-ply membranes such as TPO and PVC tend to dominate most markets, with traditional asphalt and modified bitumen roofing systems steadily losing market share due to higher installed costs and labor inputs. Although both European and North American flat roof membrane preferences appear to be converging toward single-plies, this similarity of preference has not yet extended to the underlying roof insulation. In North America, polyisocyanurate insulation (also known as polyiso or PIR) has been the dominant roofing insulation for many decades, with over 70% market share of low-slope roofing applications. Across Europe, however, the insulation with the largest low-slope roof market share is mineral fiber, also known as mineral wool or rock wool. However, the use of polyiso is growing quickly, spurred by the addition of new European manufacturing capacity and increasing demand for improved thermal efficiency.

Within Europe, the German market is typical of the general preference for single-ply membranes (in this case, PVC), accounting for over 70% of all flat roof installations. In addition, Germany has experienced strong growth in roof-mounted photovoltaic (PV) systems, which are typically installed directly over the same single-ply roofing membranes that dominate the market. Unfortunately, this combination of single-ply membranes and rooftop PV systems appears to have led to an unanticipated level of roof problems and failures, which in turn has resulted in the commencement of research investigations to better identify the causes and possible remedies.

According to available field reports (Hendriks, 2010; Spilker, 2012), roof system failure of the combination of single-ply roof covers and mineral fiber insulation appears to be related to one or a combination of two primary factors: 1) the degradation of mineral fiber insulation beneath the single-ply roofing membrane when subjected to moisture intrusion within the roof, and 2) the impact of roof traffic associated with the maintenance required to service rooftop PV systems.. Although their resistance to natural weathering is well established, single-ply roofing membranes are relatively soft and flexible materials. As a consequence, when the supporting insulation substrate beneath the membrane is damaged or compromised, the membrane itself may be exposed to an increased potential for punctures, cuts, and abrasions, especially around insulation joints and membrane fastener screw heads. In turn, this may lead to water leaks, additional damage to the insulation substrate, and further damage to the entire roofing system. A typical mode of roof insulation collapse followed by penetration of the roofing membrane by exposed screw heads is illustrated in Figure 1.

Figure 1:
Roof failures in single-ply/mineral wool roofs showing insulation collapse due to frequent foot traffic and the screw heads penetrating the single-ply membrane
(Source: Hendriks, 2010)

In an effort to quantify the effects of the observed insulation degradation and resultant membrane puncture, the BDA Test Institute in the Netherlands developed a walkability test method, in which an array of 16 pistons automatically compress the insulation to simulate the impact of foot traffic on the roof (Hendriks, 2010). In this “Marathon Man” test, the piston heads are coated with a rubber-like material similar to that used on the heels of work boots. The pistons compress the insulation with a pressure analogous to that seen from roof traffic, with a quarter turn to simulate natural foot movement during walking. One cycle is comprised of 16 pistons, each actuated four times in a square pattern. The results from the test are used to categorize the roofing assembly in terms of a walkability rating, from not suitable for roof traffic (a “0” rating) to suitable for daily pedestrian traffic (a “3” rating). Specific walkability test criteria are shown in Table 1.

Class	Number of Cycles	Meets Criterion	Walkability	Suitability for Roof Pedestrian Traffic
0	5	No	Not	Not suitable
1	5	Yes	Limited	Incidental pedestrian traffic during inspection and maintenance of roofing
2	10	Yes	Good	Frequent pedestrian traffic during inspection and maintenance of building services equipment
3	30	Yes	Intensive	Daily pedestrian traffic (galleries, roof terraces)

Table 1. Classification of walkability of insulation products
(Source: Hendriks, 2010)

The Marathon Man test and the walkability classification were then used to examine a number of roofing assemblies using different combinations of European membranes and insulations to understand how they may hold up to roof traffic. The results are shown in Table 2.

Insulation	Membrane	Rating	Walkability	Suitability for roof Pedestrian Traffic
Mineral fiber (standard)	Single-ply (EPDM)	0	No	Not suitable
Mineral fiber (standard)	Single-ply (PVC)	1	Limited	Incidental pedestrian traffic during inspection and maintenance of roofing
Mineral fiber (double density)	Single-ply (EPDM)	1	Limited	Incidental pedestrian traffic during inspection and maintenance of roofing
Mineral fiber (double density)	Asphalt (2-layer modified bitumen)	2-3	Good to intensive	Frequent to daily pedestrian traffic
Expanded polystyrene (light facing, low density)	Single-ply (EPDM)	1	Limited	Incidental pedestrian traffic during inspection and maintenance of roofing
Expanded polystyrene (light facing, low density)	Single-ply (PVC) or asphalt (2-layer modified bitumen)	2-3	Good to intensive	Frequent to daily pedestrian traffic
Expanded polystyrene (standard facing and density)	Single-ply (EPDM)	2	Good	Frequent pedestrian traffic during inspection and maintenance of building services equipment
Faced polyurethane and expanded polystyrene (heavy facing, high density	Single-ply (EPDM)	3	Intensive	Daily pedestrian traffic (galleries and terraces)

Table 2. Walkability ratings for different membrane/insulation combinations
(Source: Hendriks, 2010)

As illustrated in Table 2, membranes that are stiffer, thicker, or heavier tend to improve walkability ratings over all insulation materials. In addition, mineral fiber insulation does not appear to perform as well in the walkability test compared to polyurethane (polyiso) and medium to high-density expanded polystyrene.

Because this initial testing did not fully explain the observed roof failures, an additional test was performed in which the mineral fiber insulation was exposed to water vapor at 70°C (158°F) for 48 hours, to simulate the effect of water vapor under the roofing membrane. The results are shown in Table 3.

Test Specimen	Compressive Strength in psi (kPa)		
	Initial	After moisture load (70°C, 48 hrs, 95% RH)	After moisture load and 30 cycles of walking load
1	7.96 (54.9)	4.90 (33.8)	0.29 (2.0)
2	7.53 (51.9)	4.92 (33.9)	0 *
3	7.66 (52.8)	4.74 (32.7)	0 *
Mean	7.68 (53.0)	4.78 (33.0)	0.29 (2.0)
Change	-	-37.8%	-96.2%

**not measurable due to destruction of the test specimen*

Table 3. Change in compressive strength of mineral fiber insulation after moisture exposure, and after applying the walking load
(Source; Hendriks, 2010)

As illustrated in Table 3, the mineral fiber insulation lost over 37% of its mean compressive strength after 48 hours of moisture exposure. When the Marathon Man Test was subsequently applied, the mineral fiber insulation effectively lost all its compressive strength, in fact so much so that some of the samples could not even be measured. According to the researcher, this result was believed to illustrate the basic cause of the numerous roof failures previously reported in the field.

A Study of Moisture, Traffic, and North American Roofing Materials

Because the results and conclusions presented in the introduction to this study are applicable to materials manufactured in Europe, it was not known if similar materials manufactured in North America would exhibit the same behaviors. In order to examine the application of these materials in North America, PIMA commissioned additional testing using mineral fiber insulation and single-ply TPO membrane manufactured in North America. Testing was conducted in 2014 by Kiwa BDA Testing, B.V., using North American-produced roofing samples, and the results of this testing are contained in this report. (See Hameeta, 2015, for the complete test report.)

Sample Selection

Two different samples of common mineral fiber insulation and single-ply roofing membrane were purchased in from commercially available sources in North America. The mineral fiber samples selected were:

1) A 1” thick mineral fiber roof cover board with a density of 12.5 lb/ft^2. This product is frequently used as a cover board over other types of thermal insulation.
2) A 2” thick mineral fiberboard with an upper bitumen-impregnated layer with a density of 13.75 lb/ft^2. This product is frequently used in total thicknesses up to 6” as a combination thermal insulation/cover board material.

The single-ply roofing membranes selected were:

1) A 45-mil thickness of reinforced TPO membrane.
2) A 60-mil thickness of reinforced TPO membrane

Additional information about each sample selected—including brand name, manufacturer, and production codes—are provided in Table 4.

Product Type	Product Description	Trade Name	Production Date/Code
Mineral fiber insulation	12.5 lb/ft^2 density (Nominal 1"' thickness)	Monoboard	01.03 141019-08
	13.75 lb/ft^2 density* (Nominal 2" thickness)	TopRock DD	01.03 141005-10
Single-ply Membrane	45-mil reinforced	TPO 45 mil	20140227 0202-1029
	60-mil reinforced	TPO 60 mil	20141006 2326-1029

*Upper bitumen-impregnated layer of material

Table 4. Commercially sourced North American products used in this study

Sample Preparation and Initial Conditioning

Samples of the mineral fiber insulation were overlaid with the TPO membranes and conditioned for at least 6 hours at 73°F (23°C) at 50% relative humidity. The board thicknesses were determined using test method EN 823.2013 and the compressive strengths were determined using test method EN 826.2013 at a 10% deformation.

Compressive Strength and Walkability

Table 5 shows the compressive strength and thickness data for the mineral fiber insulation boards, both initially and after 10 cycles of the walkability test.

5.1. Walkability of 12.5 lb/ft^2 Density Mineral Fiber + 45-mil TPO

Test Specimen	Results			
	Initial		After 10 Cycles	
	Compressive strength at 10% strain in psi (KPa)	Thickness (in)	Compressive strength at 10% strain in psi (kPa)	Thickness (in)
1	18.7 (128.9)	1.10	14.0 (96.7)	1.02
2	16.4 (112.8)	1.12	14.1 (97.3)	1.00
3	13.9 (96.1)	1.04	16.8 (115.8)	1.00
Mean	16.3 (112.6)	1.09	15.0 (103.3)	1.01
Change	-	-	-8.0%	-7.3%

5.2. Walkability of 12.5 lb/ft^2 Density Mineral Fiber + 60-mil TPO

Test Specimen	Results			
	Initial		After 10 Cycles	
	Compressive strength at 10% strain in psi (kPa)	Thickness (in)	Compressive strength at 10% strain in psi (kPa)	Thickness (in)
1	18.7 (128.9)	0.98	14.4 (99.5)	1.08
2	16.4 (112.8)	1.09	17.4 (120.1)	1.02
3	13.9 (96.1)	1.10	14.4 (99.1)	1.03
Mean	16.3 (112.6)	1.06	15.4 (106.2)	1.04
Change	-	-	-5.5%	-2.0%

5.3. Walkability of 13.75 lb/ft^2 Density Mineral Fiber + 45-mil TPO

Test Specimen	Results			
	Initial		After 10 Cycles	
	Compressive strength at 10% strain in psi (kPa)	Thickness (in)	Compressive strength at 10% strain in psi (kPa)	Thickness (in)
1	12.1 (85.2)	1.98	9.7 (71.7)	1.93
2	10.8 (79.8)	2.07	10.4 (77.5)	1.95
3	10.7 (78.9)	2.00	9.3 (69.2)	1.95
Mean	11.7 (80.6)	2.02	10.6 (72.8)	1.94
Change	-	-	-9.7%	-3.9%

5.4. Walkability of 13.75 lb/ft^2 Density Mineral Fiber + 60-mil TPO

Test Specimen	Results			
	Initial		After 10 Cycles	
	Compressive strength at 10% strain in psi (kPa)	Thickness (in)	Compressive strength at 10% strain in psi (kPa)	Thickness (in)
1	12.1 (83.2)	2.04	11.3 (77.7)	1.98
2	11.6 (79.8)	2.05	9.3 (63.8)	1.99
3	10.7 (78.9)	2.02	10.9 (75.2)	2.00
Mean	11.7 (80.6)	2.04	10.3 (72.3)	1.99
Change	-	-	-10.3%	-2.5%

Table 5. Results of compressive strength and walkability testing for mineral fiber insulation/TPO combinations

The data in Table 5 indicate that 10 cycles of the walkability test reduce the compressive strength of the12.5 lb/ft^2 density mineral fiber/45-mil TPO combination by approximately 8%, while the compressive strength reduction for the 13.75 lb/ft^2 density mineral fiber/45-mil TPO combination is approximately 6%. For the 12.5 lb/ft^2 density mineral fiber combined with either 45-mil or 60-mil TPO, 10 cycles of the walkability test reduce compressive strength by approximately 10%.

Effect of Moisture on Compressive Strength and Walkability

Using the previously discussed test method developed for European products to help understand observed roof failures, testing was conducted for mineral fiber insulation after exposure to water vapor. The mineral fiber insulation boards were exposed to moisture by applying a 50°C (90°F) difference between the upper and lower surfaces of the board at 95% relative humidity for 48 hours. After exposure to water vapor, the material was dried until constant mass was achieved, and then conditioned for a minimum of 6 hours as before. It should be noted that only 45-mil TPO membrane was used for this testing, and the walkability testing was reduced from 10 to 5 cycles. The results of this testing are shown in Table 6.

6.1. Walkability of 12.5 lb/ft^2 Density Mineral Fiber + 45-mil TPO

Test Specimen	Results

	Initial		After 5 Cycles	
	Compressive strength at 10% strain in psi (kPa)	Thickness (in)	Compressive strength at 10% strain in psi (kPa)	Thickness (in)
1	14.8 (101.9)	1.12	2.8 (19.5)	1.05
2	13.5 (92.9)	1.10	1.7 (11.6)	0.99
3	11.6 (79.7)	1.08	1.1 (7.9)	0.95
Mean	13.3 (91.5)	1.10	1.9 (13.0)	1.00
Change	-	-	-85.8%	-9.1%

6.2. Walkability of 13.75 lb/ft^2 Density Mineral Fiber + 45-mil TPO

Test Specimen	Results			
	Initial		After 5 Cycles	
	Compressive strength at 10% strain in psi (kPa)	Thickness (in)	Compressive strength at 10% strain in psi (kPa)	Thickness (in)
1	11.9 (82.4)	1.99	1.6 (10.7)	1.93
2	11.5 (79.4)	2.04	2.3 (15.6)	1.95
3	11.5 (79.1)	2.00	1.3 (8.8)	1.93
Mean	11.6 (80.3)	2.01	1.7 (11.7)	1.94
Change	-	-	-85.4%	-3.5%

Table 6. Results of compressive strength and walkability testing for mineral fiber insulation/TPO combinations after exposure to water vapor for 48 hours

After exposure to moisture vapor and only 5 walkability test cycles, the data indicate that compressive strength drops over 85% for both the 12.lb/ft^2 and 13.75 lb/ft^2 density mineral fiber samples. This data is very similar to that observed in previous testing with European mineral fiber boards.

Walkability Ratings: North American Roofing Products

The walkability ratings for the tested systems are provided in Table 7. The data shows that dry mineral fiber insulation (never exposed to moisture vapor) has a Class 2—, or "good"—walkability rating, meaning that it may be suitable for incidental pedestrian traffic during inspection and roofing maintenance. After exposure to moisture vapor, the walkability rating is Class 0, meaning that it is not suitable for any roof traffic.

Roof System Configuration	Initial Classification	Initial Walkability	Classification after moisture load	Walkability after moisture load
12.5 lb/ft^2 density mineral fiber/45-mil TPO	Class 2	Good	Class 0	Not suitable
13.75 lb/ft^2 density mineral fiber/45-mil TPO	Class 2	Good	Class 0	Not suitable

Table 7. Walkability rating of tested roof assemblies

Discussion

The results of this study appear to validate prior work conducted using roofing materials from Europe, suggesting that mineral fiber insulation is only suitable for roofs with minimal roof traffic, such as that experienced during maintenance and inspections. Only 10 cycles of the walkability test resulted in an approximate 8% reduction in compressive strength for the 12.5 lb/ft^2 mineral fiber/45-mil TPO combination and an approximate 10% reduction for the 13.75 lb/ft^2 mineral fiber/45-mil TPO combination. This level of compressive strength reduction is slightly mitigated by the use of a thicker 60-mil TPO membrane, but the loss in compressive strength remains significant, ranging from approximately 5% to 10%.

It also should be noted that the compressive strengths measured for the mineral fiber products examined in this study, either initially or after 10 cycles of the walkability test, are significantly less than the compressive strengths provided by many other popular North American insulation materials. As an example, the compressive strength of polyisocyanurate and other rigid foam insulation boards is typically 20 psi or higher, or approximately 50% to 100% greater than the compressive strengths observed in this study. In Europe, the relatively low compressive strength of mineral fiber insulation appears to have been problematic whenever flexible single-ply membranes were directly applied over mineral fiber insulation; and the data from this study suggest such a concern may be equally valid in North America.

Perhaps the most important observation from both the current study and previous European research is the amount of degradation observed in the mineral fiber insulation after exposure to water vapor. When exposed to water vapor for 48 hours, the compressive strengths of both types of mineral fiber boards studied were reduced by over 85%. This condition was reported as the primary cause of many roof failures in Europe, and it is likely that the same effect would be seen in North America.

Conclusions

It is well known that moisture may collect inside roofing systems either from internal condensation or from external leaks. As a result, the presence of water vapor inside roofing assemblies may be relatively commonplace. The data from this study, combined with prior work done in Europe, suggest that moisture vapor may significantly reduce the compressive strength of mineral fiber insulation. And, when tested in combination with typical North American single-ply roofing membranes, the overall roofing assemblies would be classified as “not suitable for roof traffic” by the European walkability classification system. Therefore, great care should be taken when using mineral fiber insulation if any significant level of roof traffic and/or internal moisture is anticipated.

References

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