Study of Polyisocyanurate Rigid Foam Board Facer Behavior Using The Rolling Load Emulator

René M. Dupuis¹, John B. Letts² and Tim D. Tackett³

Key Words

Polyisocyanurate, rolling load emulator (RLE), facer delamination, load-deflection, calibration, repeatability, EPDM, compressive strength, facer adhesion

Abstract

Polyisocyanurate rigid foam roof insulation is widely used in many types of roof systems, such as mechanically fastened, adhered and loose laid assemblies. Currently, polyisocyanurate offers the highest thermal resistance per inch of thickness allowing for higher R-value in roof designs, which are limited in overall thickness. Rigid polyisocyanurate foam uses a facer sheet (both sides) for a number of reasons, including higher wind lift results and enhanced dimensional stability of the board. Facer delamination has occurred post-installation raising concerns of board integrity and wind-uplift resistance. The rolling load emulator (RLE) was introduced in 1999; limited data were available at that time regarding deflection and rebound of the facer when exposed to rolling loads. This paper discusses the load-deflection behavior of polyisocyanurate insulation of various thicknesses. Resistance to delamination was seen to be independent of compressive strength in the normal range.

RLE can be used to assess field performance (with regard to facer integrity) for foam boards of different thickness; standardization of the RLE device will assist manufacturers and users of rigid polyisocyanurate roof insulation in performing quality-control tests. This paper will discuss how the RLE has been used to assess facer integrity and the differences seen in rolling load-deflection behavior of polyisocyanurate insulation boards.

Author Biographies

René M. Dupuis

René Dupuis received his B.S., M.S. and Ph.D. in Civil Engineering from the University of Wisconsin, Madison. He began his career as a structural design engineer in private practice for Arnold & O'Sheridan, later worked as a research assistant for the Engineering Experimental Station, College of Engineering – U.W. Madison and then

¹ Principal – Structural Research Inc.

² Technical Director, Insulations – Firestone Building Products Co.

³ Laboratory Manager – Firestone Building Products Co.

taught structures and materials at SUNY – Buffalo, New York. For the past 24 years he has worked as a Principal with Structural Research Inc., conducting laboratory, field, design, research, and forensic studies on roofing materials and systems. Dr. Dupuis is an active member of ASTM since 1979 and has written numerous articles on roof material performance, testing, design along with research findings. René has served on Board of Regents with RIEI and as a technical advisor for the Midwest Roofing Contractors Association. He received the James Q. McCawley Award (1988) from the Midwest Roofing Contractors association and the Distinguished Services Citation (1995) from the University of Wisconsin – Madison for contribution to roofing industry education.

John. B. Letts

John B. Letts is the technical director of insulations in the technology department at Firestone Building Products Co. Before joining Firestone he was employed at Union Carbide, primarily in urethane technology. He received his doctorate degree in chemistry from Ohio State University in 1982. He has 17 years of experience in urethane technology, from research and development to technical service to plant support. His primary experience is in polyisocyanurate insulation board and its performance in roof systems, with extensive urethane knowledge and experience in spray, pour in place, packaging, flexible foam, elastomers and adhesives. Dr. Letts' research has focused on the chemistry, processing and application of polyisocyanurate insulation boards in roofing applications. He was the past chairman of the technical committee at PIMA (Polyisocyanurate Manufacturers Association).

Timothy D. Tackett

Tim Tackett is a foam specialist and laboratory manager in the technology department at Firestone Building Products Co. Tim began his insulation career in 1982 with the Upjohn Company's urethane division and then to Dow Chemical's plastics division in Styrofoam ® and currently Firestone Building Products Co. in polyisocyanurate board insulation. Tim has worked in manufacturing, quality assurance, technical support, research and development and plant support. He is currently involved in ASTM C16 (American Society for Testing and Materials) and in SPRI (Single Ply Roofing Industry) as task group chairman.

Introduction

A roof system depends on all components to perform. Facer integrity on a fully adhered roof is especially critical to holding a waterproofing membrane to the substrate via the insulation board. All desired attributes of a roof system, include high quality products, proper installation and periodic maintenance contribute to make a high-performing roof system. This paper deals with one aspect of the roof assembly--the performance of rigid insulation boards where a fully adhered EPDM roof membrane has rolling loads applied. A test protocol has been developed using the rolling load emulator (RLE), which measures resistance to facer delamination by applying a rolling load.

Facer delamination has occurred from time to time on all foam insulation boards utilizing facers. Although there may be reasons for delamination that are intrinsic to the physical and chemical properties of the foam, its occurrence can diminish or drastically shorten the service life of a fully adhered roof. Single-ply roof membranes directly adhered to polyisocyanurate are in wide use. Delamination of the facer, for whatever reason, causes great expense to the parties involved.

The issue of facer delamination has been with the industry for several decades. Facers are needed on polyisocyanurate insulation for a number of reasons. Large-scale commercial production would not be possible if a facer did not separate the slats in the laminator from the excellent adhesive property of the foam. Additionally, a facer spreads the fastener load through the entire board and increases board dimensional stability. Polyisocyanurate roof insulation is the lead material in use as a thermal roof insulation. In early 2002, there were in excess of 34 manufacturing plants in the United States and Canada producing polyisocyanurate roof insulation board, ranging from 0.5-inches to 4-inches (12-mm to 100-mm) in thickness.

This paper describes the efforts of one manufacturer to test for the integrity of facer adhesion from rolling loads similar to wheeled traffic on a finished roof. This research effort culminated in the construction of a mechanical testing device, which after the development issues were solved, has been instrumental in better understanding the factors affecting facer adhesion. RLE has also demonstrated usefulness in evaluating field samples of roof insulation to check for resistance to delamination from rolling loads.

Roof Construction – Fully Adhered Single-Ply Membrane

A majority of polyisocyanurate roof insulation is mechanically fastened to steel deck; a large number of mechanically fastened boards have single-ply membranes directly adhered to the facer. Rooftop traffic, especially during construction, most assuredly occurs. Wheeled traffic loads may also occur during construction. In service rooftop traffic will also occur. The intensity of traffic varies from mild to extensive depending on the buildup function and operations.

The safest way to avoid facer delamination is to use a cover board over the foam insulation as recommended by the National Roofing Contractors Association (NRCA). Many designers, contractors and building owners incorporate cover boards as their standard practice. Because of construction economics, many fully adhered single-ply membranes are installed directly to polyisocyanurate insulation without cover board protection. The vast majority of these roof systems provide good service to the owner; however, if facer delamination occurs, it cannot go uncorrected. The development of RLE came from a need to better understand facer delamination. Although many examples of facer delamination could be attributed to excessive foot traffic and/or heavy loads, there were cases where neither of these conditions appeared to be prominent. This fact, coupled with a tendency to have this problem come and go and sometimes be

more prevalent in boards from one plant versus another, motivated the research team to better understand the issue of facer delamination.

Facer delamination is defined as separation of foam from a facer. It is possible when a membrane is bonded to a facer to have separation within the facer itself. Although this is possible, it is rarely seen. It is instructive to look closer at facer delamination and define it into two types, primary and secondary. Both types have been seen in the field.

Primary Facer Delamination

Primary facer delamination typically has 1/8 inch (3-mm) or more of foam attached to a facer; most of the foam around the separation is crushed; the cells broken; and there are considerable amounts of foam dust present. In this case, excessive traffic – foot, rolling or otherwise – and/or heavy loads have contributed to this condition.

Secondary Facer Delamination

In secondary facer delamination, typically less than 1/16 inch (1.5-mm) of foam is left on the facer; most of the foam around the separation is intact; the cells are closed; and there is little foam dust. RLE is particularly useful in identifying those boards susceptible to this kind of facer delamination although it will also identify the conditions that can produce primary facer delamination.

There are two main forces acting on the board in a roof assembly: point bads, such as foot traffic, and rolling loads. There are, of course, other activities on a roof that could contribute to facer delamination, such as dropping or dragging objects across the roof assembly. The focus of our research was rolling loads for several reasons: foot traffic, although prominent, is limited in terms of the weight that can be applied; there is variability in walking styles and angle of foot deployment on the insulation and/or the membrane; it appeared to us that rolling loads were not well-understood; and in test development, it would be easier to reproduce a rolling load versus a test that would mimic foot traffic.

Background

Historically, the roofing industry has depended on compressive strength and facer adhesion to indicate board quality and delamination resistance. However, when field samples taken from problem jobs were examined, it was found most had more than 20-psi (138-kPa) compressive strength with facer adhesion above 6-psi (41-kPa), but the samples had facer delamination and, in some cases, little evidence of excessive foot traffic or heavy loads.

Two papers have reported related work in this area. In 1999, Liu and Booth¹ reported on attempts to simulate foot traffic on a roof with a replicate of a heel at different angles and measure the depth of depression as function of the number of cycles. Their main conclusions were as follows: the depth of indentation increased as the cycles increased,

and the depth of indentation decreased with the use of a cover board, as expected. However, little work was done regarding delamination though they conducted their study with two types of PVC and a modified bitumen membrane assembly.

In October 1989, a joint NRCA/Midwest Roofing Contractors Association (MRCA) Research Report² discussed the delamination effects caused by two types of gravel buggies (mechanical and hand-propelled) and the resulting effect on wind uplift. Although the weight of the buggies was given, the surface areas of the tires were not given, so it is difficult to determine the pounds per square inch applied. Additionally, all the pictures were of phenolic foam and none with polyisocyanurate. Table 3 in the report seemed to indicate damage over the polyisocyanurate with application of the buggies though this was not clear and the extent, if any, was not known.

Although we have not done any significant work related to the effect of foot traffic on facer delamination, an attempt was made to correlate the number of passes of RLE at 20-psi (138-kPa) with the walking and kneeling of a 180-pound (81.7-kg) man across the same board. To do this, a polyisocyanurate board (manufactured top) was chosen that delaminated after approximately 40 passes with greater than 25 percent delamination at 20-psi (138-kPa). This same board was cut down to 4-feet by 4-feet (1.2-m by 1.2-m) and the manufactured section of the board chosen for roof traffic so that it would be as close as possible to the facer/foam tested in the RLE sample. A board 4-feet (1.2-m) in length and approximately 6-inches to 8-inches (150-mm to 200-mm) wide was walked on back and forth in a normal gait 150 times and then back and forth on knees 50 times. The board was then examined and approximately 5 percent delamination was noted.

Care was taken to run the RLE test and the walking / kneeling test in adjoining areas in the machine direction. The distance of these foam areas from the edges of a nominal eight-foot by four-foot (2.4-m by 1.2-m) board was the same for both tests. This seemed to indicate, at least in this situation, RLE at 20-psi (138-kPa) was a more severe test than the walking and kneeling exercise of a 180-pound (81.7-kg) man. The text was conducted directly on the insulation without a membrane overlay. The board thickness was 2.7-inches (69-mm).

Correlation to Field Performance

Since 1999, all the insulation plants of a major U.S. manufacturer have used RLE as a quality control tool primarily on polyisocyanurate roof insulation boards thicker than 2-inches (50-mm). Although there are still isolated cases of delamination, the use of RLE has significantly reduced reports and claims associated with delamination in the field.

There is a range of loads on a roof. Twenty-psi (138-kPa) was chosen as the load because most boards in the Untied States are typically between 18-psi (120-kPa) and 22-psi (150-kPa).

Work in our laboratory has shown the RLE results are roughly equal or better if the test is conducted with 45-mils (114,000- μ m) thick EPDM glued to the insulation versus the same insulation without the EPDM adhered to it. Care was taken to make sure the samples were as identical as possible (aligned in the machine direction the same distance from the edge of the board) and the glue was allowed to cure for 24 hours to 48 hours. The samples with EPDM bonded to the insulation were also 3.5-inches (89-mm) wide.

Table 1 illustrates the difference between measuring the number of passes conducted in the RLE test of samples with and without 45-mil (114,000- μ m) thick EPDM fully adhered to the same insulation sample. In the case of the 4-inch (100-mm) product, adhering EPDM to the insulation almost doubled the number of passes before delamination. With the 3.2-inch (81-mm) thick board, the same trend was noted though the differences weren't as pronounced. This data indicate that adhering 45-mil (114,000- μ m) thick EPDM to insulation is less severe than running the RLE test over just the insulation at 20-psi (138-kPa). It appears the EPDM rubber cushions the load and minimizes its effect on the insulation. Fortunately, conducting the test over the insulation is also an easier test.

Table 1 – RLE Results: ISO Boards Alone vs. EPDM Adhered to ISO Boards

	No. of	Percent
	Passes	Delamination
3.2-inch (81-mm) board	98	35
3.2-inch (81-mm) board with 45-mil (114,000-µm)	182	25
EPDM adhered to the board		
4.0-inch (100-mm) board		
Specimen 1	508	0
Specimen 2	254	30
Specimen 3	500	7
4.0-inch (100-mm) board with 45-mil (114,000-µm)		
EPDM adhered to the board		
Specimen 1	512	0
Specimen 2	500	0
Specimen 3	502	0

RLE: 20-psi (138-kPa) between the knit lines

<u>Results</u>

Prior to 1999, there was no test that related directly to facer delamination. Three physical tests that may have some correlation to resistance to facer delamination include compressive strength, facer adhesion and friability. However, field samples from problem jobs have shown that areas with no delamination next to area with

delamination inevitably gave high compressive strength, facer adhesion above 6-psi (41-kPa) and acceptable friability. Although a high compressive strength board would likely not delaminate, it could be detrimental to other properties such as lower R-Value and higher costs and may be more susceptible to facer delamination albeit at a high load.

Although facer adhesion is a necessary requirement, no facer adhesion strength criteria exist that can predicate or eliminate facer delamination. Friability at the foam/facer interface may correlate to field performance, but the standard test is a bulk-form test, which doesn't correlate to resistance or facer delamination unless the entire board is friable.

RLE was the first test that seemed to correlate to field performance. An unanticipated benefit of the test was an increased awareness and concentrated effort to review all aspects of manufacturing that relates to or affects facer adhesion. Changes in formulation, processing and storage, as well as more consistent RLE testing, has led to a much greater pass/fail ratio in plant production. In fact, one plant in 2001 had a 100 percent pass percentage from RLE testing in the plant.

Since 1999, more than 15,000 RLE tests have been conducted in the manufacturing plants. This does not count the more than 1,000 tests conducted at the authors' research and development facilities.

Evaluation of insulation boards at one plant started in the fall of 1998. The following criterion was put in place: an insulation board passed the test when it survived 100 passes on RLE (at 20-psi [138-kPa]) with less than 25 percent delamination. Typically, the samples were run out to 200 passes in part to gauge how well the sample performed and get a better idea whether performance was increasing or decreasing. Although 25 percent delamination may seem excessive, it has been our experience that once delamination approaches 25 percent it will propagate quickly with continued application of load.

Positive field experience since 1998 indicates that this criteria is conservative. The criteria was set to indicate the potential for delamination, but not enough that excessive load becomes a major factor.

Limited laboratory work was done on other insulations and assemblies. In research, this unit has been used to test polyisocyanurate insulation, extruded and expanded polystyrene, siliconized gypsum board, wood fiberboard, perlite, and plywood. These materials have also been tested with EPDM, asphalt, PVC, and TPO membranes over them with differing types of adhesives and tape products, loose laid or for recover applications with gravel located under the substrate. For example, thermoplastic insulations (expanded and extruded polystyrene) deform under increasing number of passes. The extent of deformation depends on the compressive strength of the product. In another example, EPDM fully adhered to gypsum board can fracture under excessive load and delaminate.

Repeatability – Reproduceability

A hallmark of any test is consistency and reproducibility, which are concerns. Can different laboratories using the same equipment and the same sample obtain the same results? This question assumes, of course, that the equipment is equivalent to start out and the sample is equivalent. In the case of RLE, much work went into understanding what factors affect variation in the number of passes, as well as efforts to minimize their influence. Additional work went into understanding sample variability within a single board. Although a board can have variability, in most cases, it was found to be small. To better understand RLE and the issue of reproducibility, round-robin tests were conducted.

Variables were testing laboratory location, board thickness, location of a test specimen within a single board, speed and weight of the roller, and RLE modifications. The samples were tested at 20-psi (138-kPa) and were oriented in the machine direction in between knit lines. All the authors' plants participated; other participants included the authors' research and development laboratory, a vendor and an independent laboratory. Three thicknesses of board were investigated: 2-inches (50-mm), 2.7-inches (69-mm) and 4-inches (100-mm). Manufactured top, manufactured bottom and position across the width of the board were evaluated. The new versions of RLE versus the old designs of RLE were also evaluated for all thick nesses because some locations had the new RLE and other locations had the old RLE. Each testing facility tested at least 72 samples.

The following conclusions were reached regarding repeatability and reproduceability:

- 1. There was not significant difference in performance that could be correlated to lab location. Reproducibility is not an issue.
- 2. Although all samples performed well, the 2-inch (50-mm) product was slightly better than the 2.7-inch (69-mm) board, which was slightly better than the 4-inch (100-mm) board.
- 3. At least in the evaluation of these three boards (with a few isolated examples) the location of the sample taken from the full-sized board was not significant.
- 4. The speed of the roller (2 seconds versus 6 seconds versus the standard 4 seconds) was not significant.
- 5. Although there was no significant difference between the new versus the old RLE in the 2-inch (50-mm) samples, there was a marginal difference with the 2.7-inch (69-mm) samples. The new RLE was marginally more significant than the old RLE though individual samples from the same locations in the board with some laboratories did not see this difference. However, the 4-inch (100-mm) sample showed a significant difference between the old and new RLE machines. The new RLE delivered more consistent results overall.

Table 2 illustrates the greater consistency of the new modified RLE compared with the older unit. As noted earlier, the same board was used and the testing parameters were

identical. Examination of the bar graph shows that though the average number of passes weren't too far apart, the difference between the low number of passes and high number of passes, were significantly different. The new, modified RLE unit is much more consistent than the older unit. High numbers of passes (400) were used to help discern differences. Normally, the test is not run to that degree. This is not a true average because the test was stopped at 400 passes. Nevertheless, Table 2 shows a greater consistency with the new, modified unit versus the older unit.





Research Findings

A

В

Once RLE was developed, we started to evaluate RLE performance versus other parameters, such as compressive strength and facer adhesion. Table 3 indicates that no correlation to RLE performance and compressive strength exists, including facer adhesive strength. The 4inch (100-mm) sample with the higher number of passes actually had a lower compressive strength and slightly lower adhesion. It appears to us that the RLE device, along with the test protocol developed, may be closer to predicting field performance than the other two tests previously reported. The development of the RLE hardware, test setup, procedures and determination of degree of delamination can be found in Appendix A. This allows potential users of the device to have all critical information in one area of the paper for quick access and review.

Sample*	RLE	Facer Adhesion	Compressive Strength
	(Number of	(psi)	(psi)

Table 3 - RLE Performance vs. Other Foam Properties

* Nominal 20-psi (138-kPa), 4-inch (100-mm) thick board

Passes)

70

448

The RLE device can be fitted with a linear voltage differential transformer (LVDT), which, in turn, can gather deformation of the foam sample in real time. This allows foam samples 3.5-inches by 24-inches (89-mm by 610-mm) in size to be tested from different areas of a 4 foot by 8 foot (1.2-m by 2.4-m) foam board to be evaluated separately. Using this technique, it is now possible to section any part of a board for rolling load/deformation study. Figure 1 shows the rolling load/deformation performance of a 2-inch (50-mm) thick foam board from Manufacturer A. Note that a vastly different rolling load/deformation response was obtained from a 2-inch (50-mm) thick board from Manufacturer B, as shown in Figure 2. The entire cross section of each board was sampled using 13 sections, each 3.5-inches (89-mm) in width.

7.1 (49.0-kPa)

7.5 (51.7-kPa)

22.2 (153-kPa)

25.7 (177-kPa)

Figure 1 depicts a foam board that clearly demonstrates a different load/deflection response depending on the number of rolling load passes made. Figure 2 demonstrates not only uniform deflection across the board to rolling load passes but little change in deformation behavior after numerous passes. In fact, Figure 1 demonstrates a foam board with a plastic response to load/deformation, and the foam board shown in Figure 2 demonstrates elastic behavior. If repeated rooftop traffic occurs, the elastic-type performance may be more desirable.

A 4-inch (100-mm) thick foam board was sampled as shown in Figure 3 and subjected to rolling loads. The interior quadrant of the board was selected; 13 samples were evaluated. Density values were determined for all samples. Variations from 2.07 pounds per cubic foot (33.2-kg/cu m) to 2.17 pounds per cubic foot (34.8-kg/cu m) were

found. Compression strengths ranged form 21.6-psi (148.9-kPa) to 24.3-psi (167.5-kPa) among these samples as shown. The initial facer delamination is also tabulated for each of the 13 sections. Note that sample 3K and 7K were at or next to areas of low delamination resistance when compared with other areas of the board cross-section. The overall ratio on initial passes to initiate facer delamination is approximately 26:1 (sample 12 versus sample 7K).

Further study on rolling load deformation behavior is shown in Table 4, which compares three sections of the 4-inch (100-mm) board to a 2-inch (50mm) thick foam board from manufacturer D. The 4-inch (100-mm) sample had a low density, and the 2-inch (50-mm) sample had a high density. All had similar compressive strengths; however, the delamination behavior varied greatly (100 passes to 800 passes) for the 4-inch (100-mm) board.

Table 4 – Rolling Load/Deformation Comparison

Rolling Load/Deformation comparison, including delamination behavior, for 2-inch (50-mm) and 4-inch (100-mm) thick polyisocyanurate rigid foam insulation board. Manufacturer C provided 4-inch (100-mm) thick board. Manufacturer D provided a 2-inch (50-mm) thick board.

Pass No.	C-2-1 Average	C-2-6 Average	C-2-11	D-2 Average
	In. (mm)	In. (mm)	Average	in. (mm)
			In. (mm)	
0	0	0	0	0
50	0.062 (1.57)	0.068 (1.73)	0.049 (1.24)	0.055 (1.40)
100	0.092 (2.34)	0.109 (2.77)	0.073 (1.85)	0.073 (1.85)
150	0.114 (2.89)	0.144 (3.66)	0.092 (2.34)	0.085 (2.16)
200	0.130 (3.30)	0.173 (4.39)	0.111 (2.82)	0.096 (2.44)
250	0.146 (3.70)		0.128 (3.25)	0.107 (2.72)
300	0.162 (4.11)		0.145 (3.68)	0.114 (2.90)
350	0.175 (4.45)		0.162 (4.11)	0.121 (3.07)
400	0.191 (4.85)		0.176 (4.47)	0.128 (3.25)
450	0.204 (5.18)		0.189 (4.80)	0.137 (3.48)
500	0.218 (5.53)		0.203 (5.16)	0.142 (3.61)
550	0.233 (5.92)		0.214 (5.44)	0.150 (3.81)
600	0.246 (6.25)		0.226 (5.74)	0.156 (3.96)
650	0.260 (6.60)		0.238 (6.05)	0.162 (4.11)
700	0.274 (6.46)		0.253 (6.43)	0.168 (4.27)
750	0.288 (7.32)		0.267 (6.78)	0.173 (4.39)
800			0.275 (6.99)	0.180 (4.57)

<u>Specimen</u>	<u>Thickness</u>	<u>Apparent</u> <u>Overall</u> <u>Density</u>	<u>RLE</u> Load
C-2-1	4-inches (100-mm)	2.07 lb/ft ³ (33.2- kg/cu m)	23-psi (159- kPa)
C-2-6	4-inches (100-mm)	2.11 lb/ft ³ (33.8- kg/cu m)	25-psi (172- kPa)
C-2-11	4-inches (100-mm)	2.14 lb/ft³ (34.3- kg/cu m)	24-psi (166- kPa)
D-2	2-inches (50-mm)	2.48 lb/ft³ (39.7- kg/cu m)	23-psi (159- kPa)

Photograph of RLE (modified version)

Delamination

Started edge delamination at 400 passes – 36.7 percent delamination at 700 passes, 50 percent delamination at 750 passes Started edge delamination at 100 passes -&5 delamination at 150 passes, 43 percent delamination at 200 passes Started edge delamination at 600 passes – 5 percent delamination at 700 passes, 17 percent delamination at 750 passes, 27 percent delamination at 800 passes No delamination after 800 passes



<u>Summary</u>

RLE can serve dual functions by providing quality-control tests in addition to research and performance evaluation. RLE has great value as a quality-control device; current production can be evaluated for delamination resistance at the point of manufacture. RLE also supports product research; differences in delamination resistance were shown to exist within a board.

The latest version of RLE was designed for portability and consistency. The unit can be used in environmentally controlled laboratories or outdoors, inside walk-in freezers or hot rooms to test specimens in differing environments. The air regulator will allow a user to select the amount of down force applied to the test specimen for different types of material.





and a second

Figure 2 - 2 inch polyisocyanurate – manufacture B



	E Specimen Number	7 Density (lb/ft³)	Compressive Strength (psi)	Initial facer delamination (passes)		Scale: N.T.S.
Ň	13	1 2.1		220	N	Ñ
	12	2.14		650		
	11	2.14	24.3	600		
	10K	2.14		370		
	6	2.12		280		
	8	2.11		40		>
	7K	2.09		25	edge	· Vie
	9	2.11	23.4	100	9 Buc	Тор
	£	2.14		200	en al	
	4	2.11		65	l take	
	3K	2.11		125	Line	
	3	2.09		620	Spec	
	~	2.07	21.6	400	—)) = = У Ш	
3		<u> </u>			Ö	C4

Figure 3

4 inch thick polyisocyanurate insulation board

APPENDIX A

BACKGROUND ON HARDWARE DEVELOPMENT OF ROLLING LOAD EMULATOR

The RLE device is designed to predict the delamination performance of faced rigid insulation boards in field applications. This equipment was designed as a quality performance tool to be used in manufacturing and research.

Each unit weighs approximately 62-pounds (27.2-kg) and is 43 $\frac{1}{4}$ inches long by 16 $\frac{1}{2}$ inches wide and 29 $\frac{1}{4}$ inches tall (1.10-m long by 0.419-m wide and 0.743-m tall). The test unit utilizes compressed air to regulate the force applied to the test specimen and controls the traversing speed of the roller. It was designed to be a benchtop test that could be portable if necessary.

The current version is the third generation Rolling Load Emulator. Experience with the test unit has allowed it to become user-friendly, efficient and consistent. Some of the significant improvements made to the unit include:

- 1. Increasing the sample platen thickness to eliminate bowing of the platen. The sample platen was originally made out of ¼ inch (6-mm) steel. It was discovered that the platen was bowing during the test. The material was increased to ½ inch (13-mm) thick steel to eliminate any bowing.
- 2. To support the thicker platen change, the frame of the unit was changed from angle iron to tubular steel. This made the unit more durable and improved the sturdiness.
- 3. The best change was the air regulator. The first regulator was not able to maintain consistent pressure during the test, allowing a <u>+</u>7-psi (<u>+</u>48-kPa) difference from the target and made calibration of the test unit difficult. A better model replaced this regulator, but there wasn't enough improvement to satisfy repeatability studies. The final choice was a precision pressure regulator with a measuring capsule and a high gain servo amplifier. The accuracy of this regulator is 0.05 percent at midrange and a sensitivity of 0.005-psi (0.034-kPa). This regulator does not vary pressures during the test and allows the calibration to be completed quickly and accurately. The cost of this regulator is approximately 20 percent of the total cost of the entire unit. This represents the importance of a constant load during testing and calibration.
- 4. Another change involved the roller. The roller is 6.0 inches long and 3.0 inches in diameter (150-mm long and 76-mm in diameter) with the ends of the roller extending 1-inch (25-mm) beyond the specimen width on each side. Previous models used hollow core rollers that weighed between 5 and 6 pounds (2.3 and 2.7-kg). Experience found that the best performing roller consisted of a partially filled core to a weight of 20-pounds (9.1-kg). This

added additional stability to the test and eliminated some facer tears that occurred when the inertia of the roller changed directions.

- 5. The hold-down device is a simple metal bar that fits across the width of the specimen and is tightened with wing nuts. Attempts to find a better, more efficient way to hold the specimen in place resulted in an improved understanding of the importance of a secured specimen. Other devices affected the test results in subtle ways that were deleterious to repeatability. The consistency and repeatability of the test proved the holddown bar was the best decision and reproduced the holding power of the fastener and plate the best.
- 6. Another improvement involved the calibration procedure. In the early days of RLE, a platform scale was used to calibrate the down force of the roller to the test specimen. Currently, a load cell with a digital readout device is used and can be calibrated to 0.1-pounds (0.05-kg). The load button of the "Z"- styled cell was changed to a free floating ball bearing, which removes any side forces that may be applied to the load cell.

There have been many changes to the RLE since its infancy in 1996. The current unit has taken five years and more than 15,000 tests to become a reliable and consistent piece of test equipment. As mentioned earlier in this paper, several manufacturers of insulation material, suppliers and independent test facilities own at least one of these units.

In Appendix C of this paper are blueprints, which will allow anyone to build a RLE. It is the goal of the sponsors to share this technology with others to improve the entire roof insulation industry. It is also our desire to keep the test and the equipment as standard as possible so that understanding and interpretation of delamination results are the same for the entire industry. Until further discoveries are made or technology improved, those interested are encouraged to follow the blueprints carefully and not substitute or change any of the recommendations.

TEST PROCEDURE FOR USING RLE

The following test procedure is currently used by the authors' manufacturing and research facilities. As mentioned earlier in this paper, a load of 20-psi (138-kPa) was chosen because of the typical vertical compressive strength values produced by manufacturers of rigid foam insulation boards. The down force can be changed to 20-psi (138-kPa), 25-psi (172-kPa), 30-psi (207-kPa) or anything else that may be needed. For this test procedure, 20-psi (138-kPa) is the standard.

Excessive roof traffic and/or extreme point loading can cause the foam cells beneath the surface of the facer to break. The facer can delaminate from the foam core when the surface of the board is exposed to excessive roof traffic and/or extreme point loading. This test attempts to duplicate forces that contribute to facer delamination.

This test method describes the procedure for preparing and testing foam insulation board specimens for RLE properties.

TEST SET-UP FOR RLE

Prepare the RLE equipment for testing as follows:

- 1. Place the RLE unit on a strong, solid and level surface. The unit should not flex the surface on which it is sitting. The location should have an air supply and electrical outlet available.
- 2. Using a level, adjust the feet on the bottom of each corner of the frame until the unit is level in all directions.
- 3. Connect the air supply, and adjust the supply air pressure to 70-psi (483-kPa) or above. Do not change this setting after the unit is calibrated; doing so will change the traverse speed of the left and right travel.
- 4. Turn the switch that controls the left and right travel of the roller to the "On" position. At the ends of the horizontal and vertical pistons are screw adjustments that control the speed of the rollers' left and right travel, as well as the vertical movement of the roller.
- 5. Adjust the horizontal screws so that the time it takes the roller to travel is 4 +1/-0 seconds to the left and 4 +1/-0 seconds to the right (not less than 8 seconds or more than 9 seconds for two complete passes).
- 6. The vertical movement of the roller is controlled to eliminate the roller from "slamming" onto the specimen surface and having enough force to raise the roller into the fully up position without "slamming" into the up position. Slamming the roller onto the foam surface can cause damage to the cell structure just below the facer and result in premature delamination.

NOTE: Any time the test unit is moved or serviced, the steps called for in the "Equipment Set-Up" and "Calibration" sections need to be followed. Periodic equipment reviews and calibration of the test unit should be made.

CALIBRATION

The calibration procedure should not be initiated until the equipment setup process is complete. Each time the unit is calibrated, the unit must be level in all directions (see "Equipment Set-Up", Step 2).

- Place the load cell in the center opening of the load cell mounting block and attach it by placing the mounting screw through the bottom of the mounting block. Make sure the screw is snug.
 <u>Do not</u> overtighten because doing so can damage the load cell.
- 2. Place the mounting block with the load cell under the roller, and line it up between the guidelines on the sample platen or directly below the center of the roller. Tighten the setscrews located on both sides of the mounting block to the sample platen.
- 3. Take the power cord located in the lid of the shipping container, and plug it into the rear of the container where it is marked "Power". Plug the other end of the power cord into a wall receptacle (110V).
- 4. The digital readout units will display "0.0". The display unit is set to read in pounds. If anything other than "0.0" is in the display, press the tare button. If there is a message instead of a number, please refer to the enclosed manual or return to headquarters for repair.
- Lower the roller onto the load cell. Adjust the pressure gauge located on the control panel until the display reads 60.0 <u>+</u> 0.2-lbs (27.22 <u>+</u> 0.09-kg). Repeat this process a minimum of three times to verify the load.

NOTE: For an alternative method of calibration, see Appendix B at the end of this document.

SPECIMEN PREPARATION

1. Test all products greater than 2-inches (50-mm) in thickness. Cure product in the bundle one day per inch (mm) of thickness. Take the sample board at least three boards from the top or bottom of the bundle.

NOTE: It is recommended that periodic checks of thickness 2-inches (50-mm) and less than 2-inches (50-mm) be completed. If problems are detected, materials 2-inches (50-mm) and less than 2-inches (50-mm) thick should be included in the routine test procedure until compliance to quality criteria is achieved.

2. Cut a test specimen, from near the middle of the board's length, 4-inches (100-mm) wide and 24-inches (610-mm) long in the machine direction, alternating between the middle (M) of the board and operator (Op) sides of the board. For 9 of 10 tests, the specimen should be centered between knit lines. Every 10th test, cut foam specimens centered over a knit line. Specimens shall not be taken within 1-inch (25-mm) of the manufactured edge of the board.

3. Label specimens as manufactured top or manufactured bottom, with the batch code, middle (M) or operator (Op) side of the board, and note whether specimen has been centered on the knit line or between knit lines.

SPECIMEN TESTING

- 1. Place a prepared foam specimen in the specimen holder, and secure the specimen by tightening the wing nuts approximately one full turn after making contact with the specimen surface. Alternate between manufactured top and manufactured bottom test surfaces for consecutive sample boards.
- 2. Lower the roller to the specimen surface.
- 3. Set the cycle stop counter to 25; the roller will stop after 25 cycles (50 passes).
- 4. Reset the counter on the control panel of RLE unit. This counter provides the number of passes, not cycles. For example, at the end of 25 cycles, this counter should read 50 passes.
- 5. Switch the traverse switch to the "On" position.
- 6. As a minimum, check facer delamination at the end of each range of cycles (passes). When delamination is 25 percent, the test is complete.
- 7. If the specimen does not measure 25 percent delamination, reset the automatic cycle stop counter and start the roller traversing again. The specimen should be watched if delamination is present. Delamination will probably continue at an accelerated rate, possibly missing the 25 percent delamination target. Continue this process until the specimen displays 25 percent delamination or the number of passes reach 200.

DETERMINING FACER DELAMINATION

Facer delamination is determined by surface area. The test area is 12-inches by 4-inches (310-mm by 100-mm) or 48-square inches (0.0310-m). Percent delamination is defined as "the total area of facer material separated from the foam core, within a specified time in a specified test area". See Figure 5 for detailed dimensions.

1. Check delamination by using a set of thin 6-inch (150-mm) steel rulers provided with the RLE unit. The round end of the ruler will be inserted between the facer and foam. The other ruler will lie on top of the facer surface. <u>Carefully</u> probe the delaminated area while following the top of the ruler with a marker. Be sure to use a marker that is visible against the facer color.

- 2. Outline the entire delaminated area(s).
- 3. Lay the clear grid over the test area, lining up the edge of the grid with the beginning edge of the delaminated area(s) outline.
- 4. Count the number of grids (squares) that are within (inside) the delaminated area(s). Be sure to include all partial areas of squares in the total count.
- 5. Take the total number of whole and partial squares located inside the outlined delaminated area(s) and divide by 0.3. This will give you the amount of delamination as a percentage. For example, to reach a total number of squares inside the delaminated area as 8.5, (divided 8.5 by 0.3 to get 28.3 percent or 28 percent delamination).

NOTE: The process for determining delamination can be done while the specimen is still on the RLE specimen platen. This process will take some time to get used to but should take about one minute to outline the delaminated area(s) and count squares. It is recommended a mirror be placed behind the test specimen so the rear of the test specimen can be observed during the test.

REPORTING

- 1. Record the number of <u>passes</u> when the delamination occurred and the percent delamination.
- 2. Record the data. Plant personnel will then enter the data into the RLE database.

APPENDIX B

Alternative Method of Calibration for the Rolling Load Emulator

- 1. Place an accurate weighing scale (analog platform scales work fine), in pounds (kg), under the roller.
- 2. Place a piece of foam or other rigid material between the roller and scale (do not place roller directly on scale surface).
- 3. Lower the metal roller; making sure the switch is in the fully open position.
- 4. Adjust the regulated air pressure being applied to the roller until the scale gives a reading of 60-pounds (27.2-kg). Note the reading on the regulator (approximately 26.5-psi [182.7-kPa]).
- 5. Repeat step "3" (and "4" if necessary) to verify the reading. Repeat as needed to achieve the 60-pound reading on the scales. It is recommended to check the reading at least three times to verify consistency of the load.
- 6. Bring up the metal roller and remove the scale. The machine is now ready for operation.

NOTE: The use of digital platform scales is not recommended. The downward force of the roller takes a few seconds to reach full capacity from the regulator. Digital platform scales start reading the load immediately as it is applied and displays a value that is not representative of the end point of the total load applied.

The best results are achieved when using a calibrated load cell. This alternate procedure will work, but the accuracy is estimated at \pm 1 pound (0.5-kg).

APPENDIX C



TABLE OF CONTENTS:

- TITLE SHEET	 TS1
- TABLE OF CONTENTS	 TC1
- ROLLING LOAD EMULATOR	 001
- RLE EXPLODED ISOMETRIC	 002
- PARTS/MATERIALS LIST	 003
- FRAME ASSEMBLY	 004
- CONSOLE ASSEMBLY	 005
- CARRIAGE ASSEMBLY	 006
- CARRIAGE DETAIL	 007
- ACTUATOR / ROLLER ASSEMBLY	 008
- ROLLER & CARRIER DETAIL	 009
- PNEUMATIC TUBING SCHEMATIC	 010

	SCALE: AS SHOWN	SHEET NO:
ROLLING LOAD EMULATOR	JOB #: 0147	
PLANS & DETAILS	BY: SAM	ITC1
	DATE: 05/09/02	



DATE:

05/09/02



PARTS/MATERIALS LIST:

NO.	QTY.	DESCRIPTION	SUPPLIER/PART NUMBER
1	1	4" Dia. Dial Gauge- Adj. Pressure	Omega Eng. #PRG501-60
1a	1	Pressure Regulator	Omega Eng. #PRG101-60
2	1	Compressed air regulator, 12 CFM flow cap	McMaster - Carr
3	1	SS air actuator, double acting, nose mt 1.5" bore, 14" stroke	McMaster - Carr
4	1	SS air actuator, double acting, flange mt 1.5" bore, 4" stroke	PrimTech #SMC VM34AB
5	40ft	MM poly tubing, ether-based, 2.4mm IDx4mm OD, .8mm wall	McMaster - Carr
6	1	Directional valve, DBL air operated, 5 port/2 position	McMaster - Carr
7	4	Flow control	PrimTech #SMC NAS2201F-NO1-03S
8	1	Hand valve	PrimTech #SMC NVH202-NO2-HADN
9	2	Cam valve	PrimTech #SMC NVM131-NO1-01
10	11	Fittings	PrimTech #SMC KQH03-34S
11	5	Fittings	PrimTech #SMC KQH03-35S
12	2	Fittings	PrimTech #SMC KQH03-32
13	2	Union "Y"	PrimTech #SMC KQU03-00
14	1	Union elbow	PrimTech #SMC KQL03-00
15	1	Valve	PrimTech #SMC NVM130-N01-00
16	2	UCI SMB - 1 bronze muffler 1/8	PrimTech
17	1	PHD linear slider	Neff Eng. #SED-25X8
18	1	Parker H2C nipple 1/4" NPT	PrimTech
19	2	1"Ø x 18" long precision solid steel shaft.	McMaster Carr
20	2	Fixed alignment bearing, flange mt	McMaster Carr
21	2	Steel ball bearing, double sealed bearings for 5/8"Ø shaft.	McMaster Carr
22	1	5/8"Ø x 7" long precision steel shaft	McMaster Carr
23	1	4"Ø x 6" long steel roller. Weight not to exceed 5 lbs.	
		Surface on the OD to be a 2STP1/51T knurl.	
24	1	1/2" x 3/4" x 6-1/2" steel fabricated alignment assembly	
25	2	2" x 3/4" x 15" aluminum fabricated end plates	
26	1	4" x 3/4" aluminum fabricated carrier mounting plate	
27	1	1" x 1" x 1/8" sq. tube steel fabricated frame with	
		1/2" x 6" x 32" steel plate	
28	2	1/4" x 1" x 6" steel fabricated hold down	
29	4	3/8-16 wing nuts	
30	4	38-16 all thread	
31	8	1/4-20 x 1 1/4" socket head cap screws and nuts	
32	2	6-32 x 1" socket head cap screws	
33	8	8-32 x 1" socket head cap screws	
34	4	8-32 x 1 1/2" socket head cap screws	
35	8	10-32 x 1" socket head cap screws	
36	2	8-32 nuts	
37	1	1/4" pipe coupling	
38	1	1/4" pipe nipple	
39	4	3/8-16x 3/8" long setscrew	
40	1	3/8-16x 1 1/2" long carriage bolt	
41	1	8901D Self powered Totalizer	Fargo Control #100330D
42	1	SMP 302 NO Counter pick-up	Fargo Control #53394
43	2	M302 Magnet	Fargo Control #53414
-			

 ROLLING LOAD EMULATOR
 SCALE:
 AS SHOWN
 SHEET NO:

 JOB #:
 0147
 BY:
 SAM
 OOO3

 DATE:
 05/09/02
 05/09/02
 OOO3



	SCALE:	AS SHOWN	SHEET NO:
ROLLING LOAD EMULATOR	JOB #:	0147	
PLANS & DETAILS	BY:	SAM	I 004
	DATE:	05/09/02	



	SCALE: AS SHOWN	SHEET NO:
ROLLING LOAD EMULATOR	JOB #: 0147	
PLANS & DETAILS	BY: SAM	$\parallel 005$
	DATE: 05/09/02	





	SCALE:	AS SHOWN	SHEET NO:
ROLLING LOAD EMULATOR	JOB #:	0147	
PLANS & DETAILS	BY:	SAM	007
	DATE:	05/09/02	







References

¹ Liu, K. and Booth, R.J.; "Damage to Thermal Insulation Foams in Low-Slope Roof Systems Caused by Simulated Foot Traffic;" Journal Thermal Envelope & Building Science, Volume 22, Technomic Publishing Co., Inc., April 1999.

² "Result of Crushing, Membrane Adhesion and Uplift Tests on Phenolic and Polyisocyanurate Foam Roof Insulations;" Midwest Roofing Contractors Association and the National Roofing Contractors Association, Rosemont, Illinois, October 1989.