MECHANICAL PROPERTIES EVALUATION OF POLYISOCYANURATE ROOF INSULATION BLOWN WITH CFC-11 SUBSTITUTES

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A Joint Government-Industry Research Project was established to evaluate the technical viability of HCFC alternative blowing agents for polyisocyanurate foam roof insulation. One aspect of the research project is the evaluation of mechanical properties of experimental polyisocyanurate insulation blown with different potential CFC-11 substitute blowing agents.

Since roof insulation is typically the foundation for the roof membrane, it is important for the insulation to possess adequate mechanical properties. Roof application is very demanding on these properties, due to exposure to hot bitumen, solvent-bearing adhesive or high, concentrated loads from application equipment. Accordingly, this paper reports on the aspect of the joint research project which evaluated the response of experimental polyisocyanurate foam roof insulation to full scale roof application.

The experimental boards were utilized in EPDM (single-ply) and built-up roof systems. The roof systems and application techniques are described, along with observations made during application. Conclusions regarding the technical viability of HCFC alternative blowing agents with respect to suitable mechanical properties of polyisocyanurate foam roof insulation are presented.

KEYWORDS

Blowing agent, CFC, chlorofluorocarbon, HCFC, hydrochlorofluorocarbon, mechanical properties evaluation, polyisocyanurate roof insulation.

INTRODUCTION

In response to the 1987 Montreal Protocol, a Joint Government-Industry Research Project was established in early 1989 to evaluate the technical viability of hydrochlorofluorocarbon (HCFC) alternative blowing agents for polyisocyanurate foam roof insulation, which is presently blown with chlorofluorocarbon (CFC-11). The joint research project includes evaluation of thermal properties, combustibility and mechanical properties. Combustibility evaluations will be conducted in 1991. Thermal properties evaluations began at Oak Ridge National Laboratory (ORNL) in July 1989, and are reported upon elsewhere in these Proceedings in a paper by D.L. McElroy. Previous papers have also reported on thermal properties and other aspects of the research project.[1] This paper reports on mechanical properties evaluations, which were conducted in June 1990 on a specially constructed Roof Mechanical Properties Research Apparatus (RMPRA) at ORNL.

Blowing Agents

Two potential alternative blowing agents have been identified: HCFC-123 and HCFC-141b. Experimental polyisocyanurate insulation boards were blown with these two agents, along with boards blown with a 50/50 blend and a 65/35 blend of 123 and 141b. Experimental boards were also blown with CFC-11 to serve as a control. (These CFC boards are considered "experimental" because they were based on a generic formulation.) The HCFC-123 and 141b boards, along with the CFC-11 control boards, were manufactured in June 1989. The boards with 50/50 and 65/35 blends were manufactured in December 1989.

Board Characteristics

Except for the blowing agent itself, all five types of experimental boards (123, 141b, 50/50, 65/35 and 11) were produced utilizing the same generic formulation, which was designed to be representative of current technology. All boards measured 4 ft. by 8 ft. and were 1-1/2 inches thick. All boards were faced on each side with an organic/inorganic fiber product. The boards had a design core density of 1.9 pounds per cubic foot and a compressive strength of 16.0 pounds per square inch, minimum. They were all produced on a production line facility by Atlas Energy Products (a Polyisocyanurate Insulation Manufacturers Association member), utilizing a restrained rise laminator.

After board production, several boards of each type of blowing agent were perforated. This work was performed by the RMPRA contractor. The perforations were made on both board faces with a 3- or 4-penny nail. The perforations, less than 1/16 in. deep, were made on a grid that measured 1-1/8 in. by 1-1/8 in. Both perforated and unperforated insulation boards were installed on the RMPRA.

Importance of Mechanical Properties

In most low-slope roof systems, thermal insulation provides the substrate for the roof membrane. Hence, as the membrane foundation, the insulation's physical properties play a key role in the ultimate service life of the membrane. It is therefore important for the insulation to possess certain critical attributes, and to maintain them over the roof's service life. During the roof's service life, the short time period in which application occurs is typically the most demanding time for insulation. Roof application subjects insulation to rather severe conditions, such as exposure to hot bitumen, solvent-bearing adhesives, and high, compressive, concentrated loads from application equipment.

Utilization of the RMPRA

To augment laboratory characterization and analysis of the experimental polyisocyanurate foam insulation blown with HCFCs, the RMPRA was constructed to permit full scale EPDM (single-ply) and built-up (BUR) roof applications using various common application techniques. Roof application on the RMPRA has allowed evaluation of the potential susceptibility of polyisocyanurate foam blown with the various alternative agents to damage from the rigors of roof application. The RMPRA is also equipped with instrumentation to augment thermal properties evaluation that is being conducted on other facilities at ORNL.

This paper describes the RMPRA, the roof systems that were installed upon it, application techniques that were utilized, observations and testing during application and conclusions.

The joint research project is sponsored by the Society of the Plastics Industry - Polyurethane Division (SPI/PD), the Polyisocyanurate Insulation Manufacturers Association (PIMA), the National Roofing Contractors Association (NRCA), the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA). The project is under the direction of a Steering Committee, which is composed of representatives from each of the sponsors and from ORNL.

PHYSICAL CHARACTERISTICS OF THE RMPRA

The RMPRA is located in Oak Ridge, Tenn., at ORNL. It is about 100 ft. from ORNL's Roof Thermal Research Apparatus (RTRA), as shown in Photo 1. The RTRA is utilized in the joint research project for evaluation of thermal properties. The RTRA and RMPRA are situated in a manner that allows roofs on both facilities to receive essentially the same solar exposure.

The RMPRA has a plan dimension of 32 ft. by 72 ft. It is a one- story building that projects about 5 ft. above grade. The apparatus is equipped with heating and cooling equipment that will maintain an interior temperature of approximately 75°F year-round. The heating and cooling system was activated on Aug. 23, 1990, approximately two months after application of the roof (during this two month period, the interior temperature of the apparatus was not controlled). The roof structure was designed for 20 pounds per square foot live load. Half of the structure was designed for a roof covering (membrane and insulation) load of 10 pounds per square foot (psf), while the other half was designed for 19 pounds per square foot. In addition to the roof covering load, the total design dead load included an allowance of 10 psf for the weight of the deck, joists, and electrical and mechanical equipment hung from the deck or joists. The deck is 22-gauge galvanized steel, 1-1/2 in. deep, with a wide rib.

The deck is supported by steel joists spaced at 6 ft. 3 in. on center, which is the maximum permitted span for this type of deck per the 1990 Factory Mutual Research Corp. Approval Guide. The deck panels are 30 in. wide and are fastened along the side laps with one ¾ in. long -12 TEK screw located between each joist. The panels are welded to the joists with a 5/8 in. puddle weld with welding washers, four welds per sheet width. The deck is sloped at ¼ in. per foot, as shown on the roof plan (Figure 1). The slope was provided by varying the height of the bearing walls.

The steel joists span 30 ft. 8 in. and are supported by bearing walls constructed of 8 in. thick reinforced concrete masonry units. In the area with a roof covering design load of 10 psf, 20H6 joists were used. In the area with a roof covering design load of 19 psf, 20H7 joists were used. The joists were designed to have a maximum deflection under full design live and dead loads of L/240.

The design intent for the roof deck and joists was to comply with the minimum requirements of the Steel Deck Institute Design Manual (1989 edition) and the FM Approval Guide, while obtaining maximum permitted deflection. A deck/joist system meeting this criteria would result in a flexible (bouncy) deck, which would exacerbate loads on the insulation during application, thus exposing the insulation to severe loading conditions of the type that could reasonably be anticipated in many typical roofing projects.

The design loads of 10 psf and 19 psf for the roof coverings were heavier than required for the systems installed. The 10-pound and 19-pound loads were used because the RMPRA is a permanent structure and will likely be used for many different roof research projects in the years ahead. Hence, half of the deck was designed to accommodate an aggregate-surfaced BUR and half of it was designed to accommodate a single-ply system ballasted with normal weight concrete pavers, should either of these types of systems be desired in future evaluations. This difference in roof covering weight did not affect the deck panel, and only had minor influence on the joists.

ROOF SYSTEM DESCRIPTION

Two types of membrane were installed, with each membrane having two variations (Figure 2). The roof deck was divided in half by a 12 in. high wooden control curb. On one side of the curb, a built-up membrane system was installed. An EPDM system was installed on the other half of the deck. All five types of experimental boards were incorporated into both of the BUR and EPDM systems. Each system utilized two layers of insulation, for a total insulation thickness of 3 in. A portion of each system utilized insulation boards with perforated facers.

BUR System Variations

The BUR system has two variations. Half of the BUR system had three fiberglass ply sheets fully adhered directly to the insulation with hot asphalt. The other half of the BUR system utilized a fiberglass vented base sheet that was spot mopped to the insulation with asphalt, followed by two fiberglass ply sheets. Both variations used asphalt that was to comply with ASTM D 312, Type III. However, as described later, testing revealed that the asphalt was a Type IV. Both variations were surfaced with a glaze coat.

With each variation, the first layer of insulation was mechanically attached with screws and plates in accordance with FM I-60. The second layer was attached with hot asphalt.

The asphalt temperature for membrane application was targeted for the equiviscous temperature (EVT), ±25°F. The asphalt that was used had an EVT of 440°F, hence the targeted window of application temperature was 415°F to 465°F.

For insulation attachment with asphalt, the targeted application window was reduced by 25°, thereby giving a window of 390°F to 415°F. However, as described later, a greater window was ultimately used for the asphalt that was used to adhere the insulation.

EPDM System Variations

The EPDM system also has two variations. Both variations used black 45 mil EPDM complying with ASTM D 4673, Type I, Grade 2, Class U. Half of the EPDM system was fully adhered with adhesive applied directly to the insulation. The other half of the EPDM system was mechanically attached, using a spot attachment system. A continuous termination bar was installed at the interface between the fully adhered and mechanically attached systems.

With each variation, both layers of insulation were attached with screws and plates in accordance with FM I-60.

During application/testing, an aggregate ballasted EPDM system was simulated, as described later. However, the ballasted system was removed after testing and replaced with the mechanically attached system.

In general, the BUR and EPDM systems were installed in accordance with good, commonly accepted industry practices and manufacturer's recommendations. However, some exceptions were made to accommodate the research nature of the project. For example, the insulation boards were not staggered. This was done to simplify the taking of samples. Also, with the BUR systems, the membrane was applied directly to the insulation, rather than to a thin cover board as recommended in NRCA Bulletin 9 (September 1988). By applying the membrane directly to the experimental insulation, it was believed the insulation would be subjected to a more severe temperature regime during application. Since built-up membranes are sometimes applied directly to polyisocyanurate, irrespective of Bulletin 9, the more severe temperature regime testing was deemed reasonable.

ROOF SYSTEM APPLICATION

The BUR and EPDM systems were applied by the same roofing crew, which was knowledgeable of BUR and EPDM application. The BUR systems were installed on June 26, 1990. The EPDM systems were installed the following day. On both days, it was sunny and the winds were calm. Temperatures ranged from the mid-80s to the mid-90s. However, the black BUR surface had a temperature of approximately 180°F. Humidity was less than 50 percent. Several observers of the project steering committee were present to direct the testing and record the observations.

Except for the experimental insulation boards, all other roofing materials were commonly available commercial products and were obtained by the roofing contractor. All of the roofing materials appeared to be dry (within their equilibrium moisture content) at the time of application.

ROOF SYSTEM INSTRUMENTATION

Thermal instruments were placed in one 123, 141b, and CFC-11 board at the BUR section with plies direct to the insulation, and at the fully adhered EPDM section (Figure 2). At each of these six boards, heat flux transducers and thermocouples (unshielded Type T, copper constantan, 26 gauge) were placed in the boards by ORNL personnel. The boards were then carefully installed by the roofing contractor. During application of the BUR, the instruments were activated, as described later.

The instruments will permit monitoring of the thermal performance and temperature of the 123, 141b and CFC-11 boards during the RMPRA test time period. The data collected will provide a valuable comparison of results with those obtained from the RTRA and laboratory testing. The particular focus of the data from the RMPRA will be to determine aging (thermal drift) differences of the boards encapsulated on both sides with asphalt and coated on one side with EPDM adhesive, versus boards in the RTRA that do not have any encapsulent.

TESTING DURING APPLICATION

During application, a number of tests were conducted to attempt to determine if the various experimental insulation products behaved differently from one another. Tests were conducted on the insulation's susceptibility to damage from hot asphalt, susceptibility to damage from EPDM bonding adhesive and susceptibility to crushing by application equipment. The following information on temperatures, dimensions and weights is approximate. Unless otherwise noted, all asphalt temperatures were taken in the mop cart with an Omega 871 digital thermometer (probe type).

Hot Asphalt

Insulation Application—After mechanically attaching the first layer of insulation to the eastern half of the roof deck, the second layer of insulation was attached with hot asphalt. Each mechanically attached board was mopped over its entire surface, prior to installing the next board. Work commenced at the south roof edge and progressed from west to east (Figure 1). The layout of this first strip of boards was designated as "Strip 1." Strip 2 was adjacent to Strip 1, and it also progressed from west to east. Strips 3 and 4 progressed in the opposite direction, from east to west. Strip 4 was adjacent to the north roof edge. All strips were 8 ft. wide, and there were two boards of each type of blowing agent in each strip, except for the CFC-11 control. There was only one CFC-11 board in each strip (Figure 1). Asphalt temperatures and board reactions were as follows:

- Strip 1 (west to east, perforated facers): 435°F, CFC-11 laid down nicely. 123 lifted up (cupped). 141b lifted slightly. 413°F, 50/50 lifted slightly. 365°F, 65/35 laid down nicely.
- Strip 2 (west to east, non-perforated facers): 440°F, CFC-11 laid down nicely. 123 developed blisters below the facer on the mechanically attached board prior to placement of the top board; the board lifted up.

After observing blister development under the facer, application procedures were slightly modified. Up until that point, the top board was set within a few seconds after the first board was mopped. For the remainder of the boards, several seconds elapsed between mopping and setting of the top board, in order to allow for observation of blister development.

Strip 2, continued (west to east, non-perforated facers): 405°F, the first 141b board did not blister, and it laid nicely. The second 141b board developed some blisters. 330°F, 50/50 developed some blisters. 65/35 did not blister; it laid nicely.

- Strip 3 (east to west, non-perforated facer): 440°F, 65/35 did not blister; it laid nicely. 415°F, 50/50 developed some blisters on one of the boards. 141b lifted. 300°F, the first 123 board blistered. 420°F, the second 123 developed minor blisters. CFC-11 did not blister.
- Strip 4 (east to west, perforated facer): 410°F, 65/30 did not blister. 50/50 did not blister, but there was some lifting. 141b did not blister, but there was some lifting. 123 did not blister, but there was some lifting. CFC-11 did not blister.

All boards in all strips that lifted (cupped) were repeatedly stepped-in until they were held down by the asphalt.

Summary of Observations

Three asphalt temperature measurements were taken in Strips 1, 2, and 3. In Strip 1, the range was 365°F to 435°F. In Strip 2, 330°F to 440°F. In Strip 3, 300°F to 440°F. Only one measurement of 410°F was taken in Strip 4. The temperature in the mop cart at the time the CFC-11 boards were mopped ranged from 440°F to less than 420°F. The range for the 65/35 boards was 440°F to 300°F. The range for the 141b boards was 430°F to 405°F. The range for the 50/50 boards was 435°F to 300°F. The range for the 123 boards was 435°F to 300°F.

Blister development below the facer was most pronounced on the 123 boards (Photo 2), with blisters developing even when the mop cart temperature was 300°F. Blistering occurred to a lesser degree with the 141b and 50/50 boards, with the 50/50 boards being somewhat more affected than the 141b. Blisters were not observed with the 65/35 or CFC-11 boards. All of the observed blisters were on the non-perforated facers. However, blisters may have developed on Strip 1 unobserved, since the top board on Strip 1 was placed soon after mopping.

Dimensional stability (lifting/cupping) problems were pronounced with the 123 boards. Cupping occurred about each board axis (all board edges lifted). Dimensional stability problems occurred to a lesser degree with the 50/50 and 141b boards, with the 141b boards being somewhat more affected than the 50/50. Cupping was only apparent with respect to the long axis (the board ends lifted). Dimensional stability problems were not observed with the 65/35 or CFC-11 boards.

Membrane Application—After all boards on the east half of the deck were attached with asphalt, the membrane was applied. The section receiving the vented base sheet was applied first, beginning along the north roof edge and working south (Figure 1). At this section, the insulation was spot mopped prior to setting the base sheet (Photo 3). At the base sheet laps, the mopping was continuous. Two asphalt temperature measurements were taken during the application of the vented base sheet: 460°F and 465°F (465°F was the upper end of the application temperature window). After installing the base sheet, the ply sheets were installed. Two asphalt temperature measurements were taken during ply sheet application over the base sheet: 467°F and 465°F.

After completing work on the vented base sheet section, work continued on the section with the ply sheets applied directly to the insulation. During this work, five asphalt temperature measurements were taken: 468°F, 449°F, 464°F, 461°F and 460°F.

The thermal instruments embedded in the insulation as previously described were activated during membrane application. The temperature in the mop cart just prior to mopping over the first thermocouple, which was in the 141b board, was 449°F. The mop cart was near the thermocouple. The mop glided over the insulation surface a few feet before going over the thermocouple. The thermocouple recorded a maximum temperature of about 275°F. The thermocouple in the 123 board was 8 ft. from the 141b thermocouple. The 123 thermocouple recorded a maximum temperature of about 270°F. The thermocouple in the CFC-11 board was about 8 ft. from the 123 thermocouple. The CFC-11 thermocouple reached a maximum temperature of about 250°F. Just before applying the second ply, the mop cart temperature measured 464°F. The 141b thermocouple recorded a maximum temperature of about 240°F after the first ply was mopped to receive the second ply.

Summary of Observations

During membrane application, blisters developed below the innsulation facer on the 123, 141b and 50/50 boards. All of the boards that developed blisters had non-perforated facers.

After the base sheet and two ply sheets had been applied, a blister approximately 11 ft. long and 12 inches wide was observed. It occurred over 123 and 141b boards in an area with a perforated facer. It was not determined if the blister was below the facer, between the facer and base sheet, or between the ply sheets. The blister was stepped-in while the membrane was still quite warm (above 160°F). The next day, the blister was not noticeable. This area will be sampled in the future for further analysis.

As the insulation boards were mopped, the asphalt frothed (bubbled) fairly uniformly (Photo 4). This was observed on all five of the insulation products. It occurred over the perforated and non-perforated facers, although frothing was not as pronounced over the perforated facers. Frothing was also observed earlier when asphalt was applied to the top of the mechanically attached boards.

EPDM Bonding Adhesive

Both layers of insulation were mechanically attached to the southwest quadrant of the roof deck. The EPDM was positioned over the insulation and then pulled back for adhesive application. A neoprene-based adhesive with solvent carrier was applied to the insulation and the EPDM with a roller. After the solvent flashed off, the EPDM was matted with the insulation. To perform this work, the adhesive was applied in a Strip running west to east. There were a total of three strips. The first strip was adjacent to the south roof edge. It had an open time of 30 to 45 minutes (open time is the amount of time between adhesive application and matting of the EPDM with the insulation). The second strip had an open time of about one hour. The third strip had an open time of about 15 minutes.

During adhesive application and the open time period, no differences in behavior of any of the insulation boards was observed. In the future, samples will be taken for further analysis.

Crushing

At the northeast quadrant, a crushing test was performed by loose-laying one layer of insulation (with perforated facer) over the deck. It was then rolled over with a four-wheel cart. The cart had a front wheel load of 141 pounds per wheel. The rear wheels had a load of 158 pounds per wheel. The cart had large tires, with a bearing area of approximately 8.8 square inches per tire. Hence the front wheel load was about 16 pounds per square inch (psi) and the rear load was about 18 psi. The insulation boards were chalk-lined and the cart made five passes (with both the front and rear wheels) over each board.

One 18 in. by 18 in. sample was taken from each board type and examined with an eight power magnification scope. No board damage was observed (there was no indication of crushed cells, facer delamination, or core fracture). The samples are identified as numbers 1-5 (Figure 2).

At the northwest quadrant, a simulated ballasted EPDM application was executed as follows: First, a crushing test was performed by loose-laying one layer of insulation (with perforated facer) over the deck, followed by one layer of loose-laid EPDM. This was then rolled over with a ballast buggy. The buggy had three wheels, but in all crushing tests, the middle wheel did not bear on the surface. The main wheels delivered a load of 275 pounds per wheel. The tires had a bearing area of approximately 8.3 square inches per tire, for a wheel load of about 33 psi. The EPDM was chalk-lined and the buggy made five passes over each board.

The membrane was then removed and the insulation boards liffted up and observed (on the facer and board edge). No damage was observed (there was no indication of crushed cells, facer delamination, or core fracture).

In the second phase of the crushing test, the previously tested boards were placed in their original position and again covered with one layer of loose-laid EPDM. A polyester "stone protection mat" (5.7 ounces/yard, 33 mil) was placed over the membrane, followed by a layer of rounded aggregate (ASTM D 448, Number 4) at a rate of approximately 10 pounds per square foot. The ballast buggy (with the same load noted above) then made two passes over the aggregate (Photo 5). An attempt was made to make these passes directly over the location of the previous five passes.

The aggregate and membrane were then removed and the face of the boards observed. There was minor facer damage, with the facer being depressed or ruptured in a few locations (Photo 6). There did not appear to be any significant difference in damage among the five insulation products. One 24 in. by 24 in. sample was then taken from each board type and examined with the eight power magnification scope. No board damage was observed (there was no indication of crushed cells, facer delamination or core fracture), other than for the few random depressions and facer ruptures that were caused by stones. The samples are identified as numbers 6-10 (Figure 2).

On the northeast quadrant a crushing test was performed over the BUR. The test was performed the day after the membrane had been installed and prior to glazing. The ballast buggy with the load described above made five passes over the chalk-lined membrane.

One 24 in. by 24 in. sample was taken from each board type. Because of damage around the edge during sample removal, further sample analysis will be conducted in the lab to determine if any crushing damage occurred. The samples are identified as numbers 11-15 (Figure 2).

On the southwest quadrant a crushing test was performed over the fully adhered EPDM (Figure 2). The ballast buggy with the load described above made five passes over the chalk-lined membrane. There was no apparent damage. Samples of this area will be taken in the future.

Summary of Observations

There did not appear to be any significant differences in the response of the five types of insulation boards to the crushing loads. Response to the crushing tests were what would be expected of currently available polyisocyanurate insulation, based upon previous research work.[2,3]

Commentary on the Ballast Buggy Load

The loaded ballast buggy that was used for the crushing test had a total weight of about 550 pounds, which resulted in a wheel load of 275 pounds. With a tire bearing area of 8.3 square inches, this results in a loading of about 33 psi. Other types of ballast buggies may deliver somewhat heavier loads. In previous research work,[3] a three-wheeled buggy had a total loaded weight of 990 pounds. If each wheel was equally loaded, it would deliver 330 pounds per wheel, which would equal about 40 psi if its tires had the same bearing area. In that previous research work, load distribution to the three wheels was not measured. Nor was the tire bearing area measured. It is probable that the two rear tires carried more load than the center tire. However, the two rear tires had larger bearing areas than the buggy used on the RMPRA. In summary, while the RMPRA buggy psi load may not be as large as what may be encountered with other equipment, the load was of the order of magnitude that would commonly be encountered.

ASPHALT TESTING AFTER APPLICATION

A sample of the asphalt, which was labeled as complying with ASTM D 312, Type III, was obtained prior to heating. An additional sample of asphalt was obtained from the kettle towards the end of the BUR application. Both samples were sent to Chicago Testing Laboratory for testing of penetration, softening point, flash point and viscosity.

The penetration and flash point of both samples met the ASTM specifications. However, the softening point did not. The softening point of the sample taken prior to heating was 219°F. The softening point of the sample taken after heating was 207. The maximum permitted softening point for a Type III asphalt is 205. Both samples fell within the range specified for a Type IV asphalt.

The asphalt apparently was incorrectly labeled. The cause of the fall-back in softening point was not determined, but it was not caused by improper heating.

FUTURE SAMPLING AND TESTING

In the fall of 1991, the RMPRA roof will be observed and additional samples taken. At the time of that sampling, the roof will have been exposed over one year, including two summers. Potential samples include 1) boards under the fully adhered EPDM in the area where the crushing test was performed, 2) boards under the mechanically attached EPDM in the area where the crushing test was performed (the area which simulated the ballasted EPDM application), 3) the area in Strip 4 which developed the long blister, and 4) other locations deemed appropriate.

Additional laboratory analysis of samples 6-15 will be conducted.

CONCLUSIONS

Based on the work conducted on the RMPRA, it appears that HCFC blown polyisocyanurate roof insulation can possess sufficient mechanical properties, thereby making it suitable for incorporation into BUR or single-ply roof systems.

The experimental CFC-11 boards used in this project were based on a generic formulation, which was not optimized. However, these boards responded to the application processes (hot asphalt, EPDM adhesive, crushing loads) similarly to the way in which currently available commercial polyisocyanurate boards would be expected to perform. Therefore, the generic formulation that was used for the experimental CFC-11 boards, as well as the experimental HCFC boards appears to be valid. Of course, prior to commercializing an HCFC blown polyisocyanurate product, the manufacturer would likely optimize the formulation to further improve the performance of the future commercially available HCFC blown boards.

With respect to response to hot asphalt, the CFC-11 and HCFC-65/35 boards behaved essentially the same.

The HCFC-65/35 experimental boards appeared to possess adequate tolerance to hot asphalt.

With respect to response to hot asphalt, many of the HCFC-123, HCFC-141b, and HCFC-50/50 boards experienced development of blisters below their facers. The blistering problem was most pronounced with the HCFC-123 boards. However, the extent of blistering with the HCFC-141b and HCFC-50/50 is of concern.

All of the observed blisters developed in boards with non-perforated facers.

The blistering problem needs to be further explored by manufacturers prior to the commercialization of boards blown with 123, 141b, or with a 50/50 blend. For some unidentified reason, blistering problems were not observed with the 65/35 blend. With further respect to response to hot asphalt, many of the HCFC-123, HCFC-141b, and HCFC-50/50 boards experienced dimensional stability problems. The problem was most pronounced with the HCFC-123 boards.

The dimensional stability problem needs to be further explored by manufacturers prior to commercialization of boards blown with 123, 141b, or with a 50/50 blend. For some unidentified reason, dimensional stability problems were not observed with the 65/35 blend.

With respect to EPDM adhesive and crushing resistance, the CFC-11, HCFC-123, HCFC-141b, HCFC-50/50, and HCFC-65/35 boards behaved essentially the same.

All of these experimental boards appeared to possess adequate resistance to loads commonly experienced during application.

The previous conclusions are preliminary, pending future observations after additional exposure to natural weathering and completion of additional testing.

It appears the mechanical properties evaluation on the RMPRA will make a valuable contribution to the research project that is endeavoring to find viable alternatives to CFC blowing agents for polyisocyanurate foam roof insulation.

It appears the size of the RMPRA deck was adequate for the tests performed. Except for the CFC-11 control boards, for each alternative blowing agent in each system variation, four full size 4 ft. by 8 ft. boards were used (two with perforated facers, two with non-perforated facers).

The crushing tests appear to be a suitable protocol for research purposes, not only for this project, but also for other research projects that are evaluating insulation crushing resistance. These test procedures are refinements of previous work.[2,3]

The thermocouples and heat flux transducers embedded in the six boards on the RMPRA may give some useful data on the influence of asphalt and fully adhered EPDM on thermal aging.

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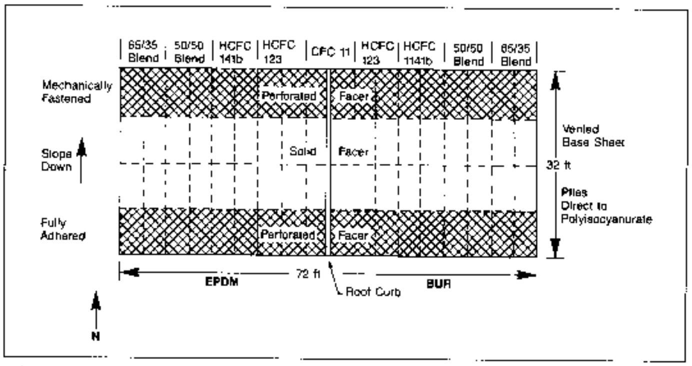

Figure 1 *RMPRA roof plan.*

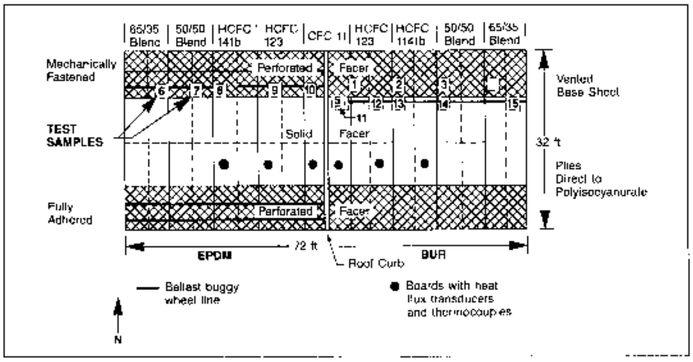

Figure 2 *Locations of samples and thermal instruments.*

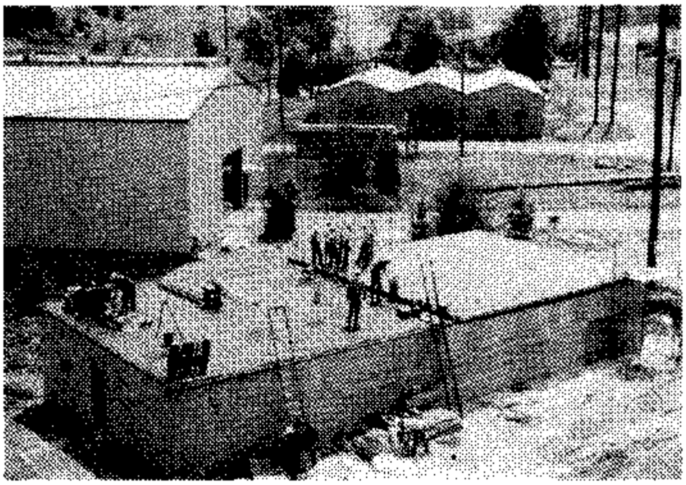

Photo 1 *View of RMPRA (looking south). BUR section is on the left. Fully adhered EPDM section is on the upper right. Mechanically attached EPDM is on the lower right. Small, low building is the RTRA.*

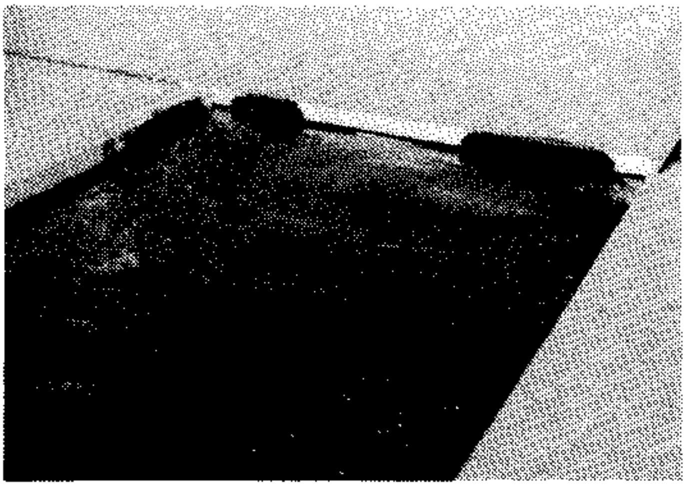

Photo 2 *Blisters developed below facter on HCFC-123 board. Note the lifting of the edge of the 123 board in the upper part of the photo.*

Photo 3 *The base sheet was attached with spot mopping of asphalt in the field of the sheet. At the laps, the mopping was continuous as shown.*

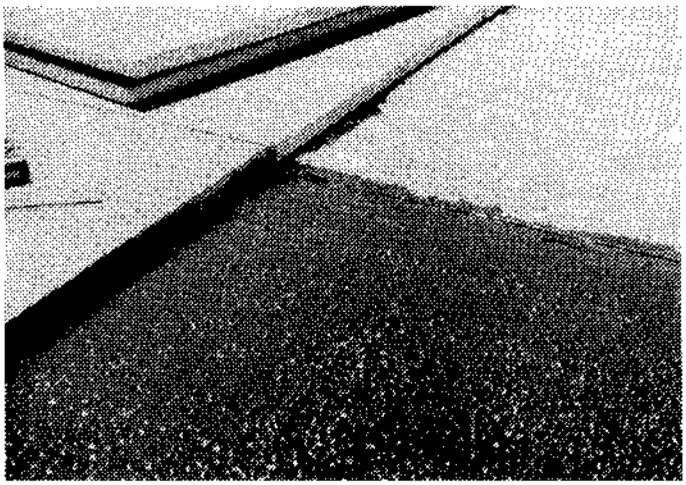

Photo 4 *Asphalt typically frothed (bubbled) when mopped over the insulation.*

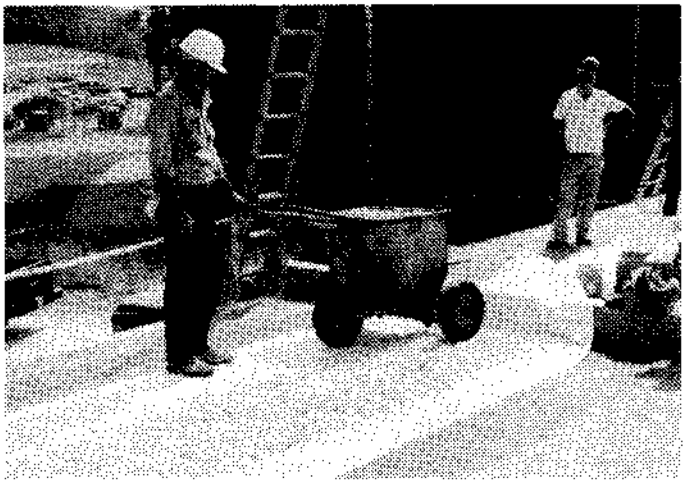

Photo 5 *Crushing test: A loaded ballast buggy made five pases over EPDM covered insulation. Filter fabric and ballast was then placed over the EPDM and the loaded buggy made two additional passes. When passing over the insulation, the middle wheel of the buggy did not bear on the roof.*

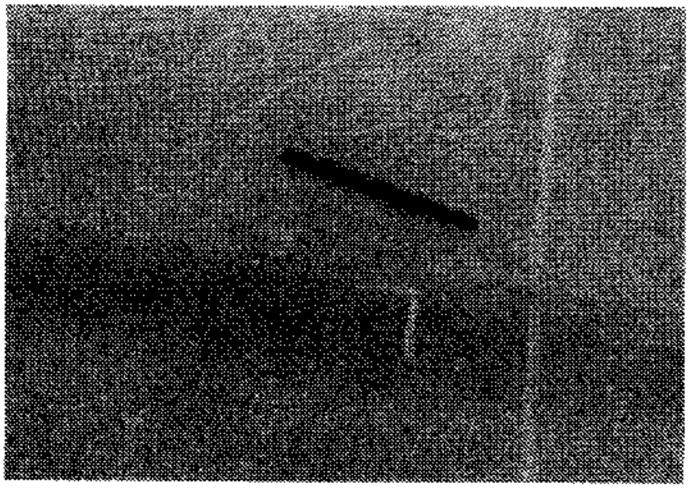

Photo 6 *After the testing shown in Photo 5, the membrane was removed to observe the insulation. The small dots are the facer perforations. The only damage in this photo, which is of sample 7, are two facer ruptures. One rupture is just above the number "7," and the other is about 2 inches to the left. An ink pen is shown for scale.*