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PERFORMANCE OF POLYVINYL CHLORIDE ROOFING: AN OVERVIEW

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ABSTRACT

This paper provides an overview of durability issues related to the performance of polyvinyl chloride (PVC) membrane roofing. The overview highlights those areas of PVC performance that have been problematic so that they can be eliminated or at least reduced significantly. Eliminating the more common, recurring problems will allow major strides to be taken toward the development of sustainable roofs. These were among the key findings noted:

- In the more than 20 years that PVC roofing has been available in North America, it has provided generally satisfactory performance, although significant problems have occurred as reported by the National Roofing Contractors Association's Project Pinpoint. Statistics are not available on the serviceability of PVC roofing.
- Over 50 percent of the problems reported by Project Pinpoint involve embrittlement and shrinkage of the membrane, which may be associated with plasticizer loss from the sheet.
- Important changes in practice have occurred, for example, the elimination of nonreinforced PVC membrane materials and ballasted systems. These changes are expected to result in an increase in the average lifetime of PVC roofing.
- Few data are available on the permanence of plasticizers versus in-service performance or laboratory evaluation of PVC membrane materials. For example, American Society for Testing and Materials (ASTM) Standard D 4434 does not include a requirement that is a direct measure of plasticizer retention after specimens are exposed to heat and ultraviolet radiation (ASTM 1995a). It is recommended that such a requirement be developed.
- Thermoanalytical techniques such as dynamic mechanical analysis and thermogravimetry are well suited for use in characterizing PVC membrane materials and changes they may undergo in service or during laboratory exposures. It is recommended that these methods be considered for incorporation in ASTM Standard D 4434.

INTRODUCTION

This paper presents an overview of durability issues related to the performance of PVC membrane roofing. According to the brochure announcing this workshop, sustainable low-slope roofing is "defined, constructed, maintained, rehabilitated, and demolished with an emphasis throughout its life cycle on using natural resources efficiently and preserving the global environment." Undoubtedly, a key characteristic of a sustainable roof is durability. In addition to cost savings, longer-lasting roofing offers the opportunity to conserve natural resources, both in the materials used in constructing the system and in the energy expended in roof manufacturing, installation, maintenance, repair, replacement, and disposal. Additionally, roofs that perform well as designed are generally energy efficient.

uncovered and ballasted samples (Rossiter et al. 1995b). Of the properties measured, only tear strength and thickness showed discrimination between the three ballasted samples and the six uncovered samples. Considerably greater increases in tear strength and decreases in thickness were determined for the ballasted samples than for those that were uncovered. It was suggested that laboratory investigations were needed to determine whether these observations were related to differences in plasticizer loss in the samples. The finding that thickness measurements showed discrimination between acceptably and unacceptably performing samples is similar to the observation of the CIB/RILEM committee (1995) that a PVC sample exposed outdoors underwent not only a relatively large change in T_g but also a relatively large decrease in thickness.

Among its many findings, the Corps of Engineers study (Rossiter et al. 1995 b) provides a reminder that although a nonreinforced membrane may not shatter, it may experience another problem—splitting—related to shrinkage and embrittlement. To date, splitting problems have not been an issue in PVC performance. Project Pinpoint lists them at about 1% of PVC problem jobs (Cullen 1993). Nevertheless, because few data are available on plasticizer loss experienced by reinforced PVC membranes in service, it would be beneficial to develop plasticizer loss data. Today's and tomorrow's PVC roofing uses only reinforced products. A recommendation is that the task group responsible for ASTM Standard D 4434 either develop a requirement that is specific to plasticizer permanence, or demonstrate the relation between plasticizer permanence and the mechanical property tests currently in the standard. The better the membrane performance properties are characterized, the better the possibility that designers and specifiers will select sustainable roofing systems.

Flashing

Flashing problems are third on the Project Pinpoint list for PVC roofing (Table 1), accounting for 15% of the reported problems. It is not surprising the flashings are high on the list, as flashings have long been recognized as perhaps the most problematic area of low-slope roof performance. Minimizing flashing problems requires paying strict attention to design details during roofing construction. Details for PVC systems are available both from manufacturers' literature and from association documents such as the NRCA Roofing and Waterproofing Manual.

It may be asked whether PVC flashing problems reported in Project Pinpoint are associated with shrinkage and embrittlement of the membrane material. Field experience has shown that shrinkage often results in excessive pulling of flashings. If this is the case, it might be expected that the changes in design practice to eliminate the use of nonreinforced materials and ballasted systems would result in a reduction of reported flashing problems.

Puncture and Tear

Puncture is the rupture of the membrane by a piercing action, often caused by a pointed or other sharp object. Tear is rupture initiated and is propagated at a site of high stress concentration caused by a cut, defect, or other localized deformation (ASTM 1995c). Although these two mechanical actions result in different modes of loss of watertightness, NRCA's Project Pinpoint surveys of problem roofing treat them collectively. Consequently, it is not known whether one is more important than the other. Collectively, 14% of PVC problem roofs are reported to have puncture and tear defects, which is comparable to the percentage of those having flashing defects (Table 1).

Puncture of a roofing membrane is characterized as being either static or dynamic. Static puncture results from concentrating loads imposed on the membrane, usually over time. Dynamic puncture is generally due to objects dropping or falling on the roof, including hail. Good roofing practice thus dictates that sources of such phenomena be minimized through actions such as using common sense in avoiding sharp, concentrated loads on the membrane, controlling access to the roof, and providing roof protection (e.g., walkways) in areas of heavy traffic. Additionally, the membrane material should have adequate resistance to puncture sources that might normally be encountered, and cannot be avoided, such as hail. On the latter subject, ASTM Standard D 4434 recently added requirements for minimum static and dynamic puncture resistance of PVC membrane materials. It will be interesting to determine whether future Project Pinpoint results show decreases in puncture (and tear) problems.

Requirements for hail resistance of PVC membrane materials have not been included in ASTM Standard D 4434. Hail tests based on impact with ice spheres or steel weights (Greenfield 1969; Koontz 1987) have been applied to roofing membrane products including PVC. If the impact resistance of PVC is an issue in regions subject to a high incidence of roof-damaging hail, these tests could provide the basis for product evaluation. The evaluations should be performed on unexposed (i.e., new) and laboratory-exposed specimens. For example, Flueler and Rupp (1986) in subjecting PVC membrane materials to hail impact, reported that hardly any decrease in impact resistance was noticed over 5 years of exposure, but by 7, 10, and 17 years, the resistance had decreased. Such findings suggest that it is important to evaluate whether the product has acceptable hail impact resistance after exposure to conditions that may result in its embrittlement. For example, the Factory Mutual Research Corporation Approval Standard 4470 (FMRC 1992) contains a requirement that the membrane (or other roof cover) be subjected to a hail resistance test both before and after 1000 hours of exposure in a fluorescent UV condensation apparatus.

Tear resistance of PVC membrane materials and its relation to in-service performance have not been addressed in the literature. Requirements for minimum tear resistance of PVC membrane materials are included in ASTM standard D4434.

Seams

Because PVC is a thermoplastic membrane material, PVC seams are normally field fabricated using heat fusion, although historically solvent welding was often performed (Marien 1982). Griffin and Fricklas (1996) have described the field seaming process for PVC (and other thermoplastics) as being relatively easy and producing dependable seams that are as strong as the sheet material itself. Evidence of the strength of PVC seams was given almost 15 years ago by Dupuis and Moody (1982), who evaluated the shear strengths of solvent welded seams. They reported that the PVC specimens failed not in the seam, but in the membrane material adjacent to the seam. Because PVC and other thermoplastics form such strong bonds, Griffin and Fricklas (1996, Chapter 13) have suggested that a weldable thermoplastic may be the membrane material of choice for installation on roofs cluttered with equipment and having numerous penetrations. With such testimony to the reliability of PVC seams, the observation that faulty seams rank among the top five defects reported for PVC roofing may appear surprising.

A reason for the relatively high ranking of reported defects for PVC seams (which are considered to be quite reliable) may be poor application. That is, proper heat fusion of the PVC sheets comprising the seam may not always be achieved during membrane application and, in the vernacular of the industry, a "cold weld" occurs. To lower the risk of seam problems (i.e., to promote the installation of sustainable PVC roofs), diligent attention to prescribed techniques for field seaming is a necessity.

As a specific illustration of the importance of proper seam fabrication, Smith (1996) reported an observation of a roof damaged by Hurricane Andrew. A section of a PVC seam in the roof debonded, and a portion of the membrane tore in that location. He attributed the failure to a poor or cold weld, as he found that "the bond was very weak." After the seam delaminated, the hurricane-force winds penetrated below the membrane and tore it in the location of the delaminated seam. More extensive, progressive failure of a larger section of the membrane probably was avoided only because the cold weld was located on the downwind side of the roof.

If it is considered necessary, PVC roofing offers an opportunity to establish a relatively rough, but seemingly practical, quality control procedure for characterizing the effectiveness of the field seaming process. During membrane installation, seam cuts may be manually pulled to determine the ease at which they may be delaminated. Because a well-made seam is quite strong (Dupuis and Moody 1982), it will generally not be possible to pull it apart by hand. Manual delamination indicates that it is defective. If manual pulling on the seam is considered to be too crude, then calibrated portable testing machines can be used in the field to measure seam strength. In this case, a properly prepared seam would be expected to demonstrate a minimum strength. Neither procedure has seen much use in North America. One author of this paper (Rossiter) has seen the manual method applied in practice by a roof contractor who indicated that the firm's mechanics routinely made cuts for manual testing to assure themselves that they were properly applying the seams. Additionally, this same author has encountered the use of a portable testing machine for PVC seam quality control in Europe. In both cases, the individuals describing these practices believed that the benefits of having semi-quantitative or quantitative evidence that the seams were properly fabricated outweighed the disadvantages of cutting and patching a newly installed membrane.

Wind Uplift

Wind uplift defects comprise the last category of problem PVC roofing that is specifically addressed by Project Pinpoint; they account for only 3% of the reported problem jobs. Such a relatively low incidence of wind uplift problems indicates that these problems are generally not due to the PVC membrane material, but are part of a larger roofing industry issue concerning the performance of single-ply membranes under wind loading. In recent years, this issue has been given considerable attention in the literature, and a review of the subject is beyond the scope of this paper. For a general overview on wind issues and roof performance, refer to the recently published text by Griffin and Fricklas (1996, Chapter 7).

SUMMARY AND CONCLUSIONS

This paper has presented an overview of durability issues related to the performance of PVC membrane roofing. It is one in a number of papers on the durability of low-sloped roofing systems presented in the Workshop on Sustainable Low-Slope Roofing. The intent is to highlight those areas of PVC performance that have been more problematic so that they can be eliminated or at least reduced significantly. Eliminating the more common, recurring problems will allow major strides toward the development of sustainable roofs.

These conclusions were drawn from the overview:

- In the more than 20 years that PVC roofing has been available in North America, it has provided generally satisfactory performance, although significant problems have occurred as reported by NRCA's Project Pinpoint. Statistics are not available on the serviceability of PVC roofing.
- Over 50 percent of the problems reported by Project Pinpoint involve embrittlement and shrinkage of the membrane, which may be associated with plasticizer loss from the sheet.
- Important changes in practice, for example, the elimination of nonreinforced PVC membrane materials and ballasted systems, have occurred. These changes are expected to result in an increase in the average lifetime of PVC roofing.
- Few data are available on the permanence of plasticizers vs in-service performance or laboratory evaluation of PVC membrane materials. For example, ASTM Standard D4434 does not include a requirement for a direct measure of plasticizer retention when specimens are exposed to heat and UV. We recommend that such a requirement be developed.
- Thermoanalytical techniques such as DMA and TG are well suited for use in characterizing PVC membrane materials and changes they may undergo in service or during laboratory exposures. It is recommended that these methods be considered for incorporation in ASTM Standard D4434.
- Commercial PVC products have been shown to be stable under commonly used laboratory heat exposure conditions (e.g., 80°C for varying lengths of time). Some evidence is available suggesting that heat exposure may not be appropriate for distinguishing between "fast-aging" and "slow-aging" products. This question warrants further study.
- Unacceptable flashing performance has been relatively high on the list of Project Pinpoint reported problems for PVC. Flashing problems might decrease in response to design steps taken to eliminate the use of nonreinforced membranes and ballasted systems.
- Seams of PVC membranes are highly reliable when properly field fabricated. Nevertheless, Project Pinpoint reports a relatively high proportion of seam problems, which are normally attributed to faulty installation. This observation emphasizes the importance of paying strict attention to details in assembling PVC seams. If warranted, quality control methods for field testing of newly fabricated seams could be initiated.

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REFERENCES

ASTM 1995a. "Standard Specification for Poly(Vinyl Chloride) Sheet Roofing," ASTM D 4434-95, *Annual Book of Standards*, Vol. 04.04, American Society for Testing and Materials, West Conshohocken, Penn.

ASTM 1995b. "Standard Terminology of Building Constructions," ASTM E 631-93a, *Annual Book of Standards*, Vol. 04.07, American Society of Testing and Materials, West Conshohocken, Penn.

ASTM 1995c. "Standard Terminology Relating to Rubber," ASTM D 1566, *Annual Book of Standards*, Vol. 09.01, American Society for Testing and Materials, West Conshohocken, Penn.

Cash, C. G., and D. M. Bailey 1993. *Predictive Service Life Tests for Roofing Membranes: Phase I*, Interim Report FM-94/03, U.S. Army Corps of Engineers, Construction Engineering Research Laboratories, Champaign, Ill., December.

Cash, C. G., and D. M. Bailey n.d. *Predictive Service Life Tests for Roofing Membranes: Phase II*, U.S. Army Corps of Engineers, Construction Engineering Research Laboratories, Champaign, Ill.

CIB/RILEM 1995. *Thermal Analysis Testing of Roofing Membrane Materials*, Final Report of the Thermal Analysis Task Group, RILEM 120-MRS/CIB W.83 Joint Committee on Membrane Roofing Systems, December. (Available from W. J. Rossiter, Building Materials Division, National Institute of Standards and Technology, Gaithersburg, Md.)

CGSB 1995. "Polyvinyl Chloride Roofing and Waterproofing Membrane," CAN/CGSB 37.54.-95, Canadian General Standards Board, Ottawa, Ontario, Canada.

Cullen, W. C. 1988. *Project Pinpoint Analysis: Trends and Problems in Low-Slope Roofing 1983-1988*, National Roofing Contractors Association, Rosemont, Ill.

Cullen, W. C. 1993. *Project Pinpoint Analysis: Ten-Year Performance Experience of Commercial Roofing 1983-1992*, National Roofing Contractors Association, Rosemont, Ill.

Flueler, P., and Fritz Rupp 1986. *The Hail Resistance of Plastic Components of the Building Shell*, Swiss Federal Laboratories for Materials and Testing, Dubendorf, Switzerland.

FMRC 1992. "Approval Standard Class Number 4470," Supplement Number 3, Factory Mutual Research Corporation, Norwood, Mass., August 29.

Foltz, S., and D. M. Bailey 1987. "Poly(Vinyl Chloride) (PVC) Roofing: Preliminary Field Test Results," pp. 63–81 in *Roofing Research and Standards Development, 2nd Volume*, ASTM STP 1088, edited by T. J. Wallace and W. J. Rossiter, American Society for Testing and Materials, West Conshohocken, Penn.

Greenfeld, S. H. 1969. *Hail Resistance of Roofing Products*, Building Science Series 23, National Bureau of Standards (now National Institute of Standards and Technology), Gaithersburg, Md., August.

Griffin, C. W. 1982. *Manual of Built-Up Roof Systems*, 2nd Ed., McGraw-Hill, New York.

Griffin, C. W., and R. Fricklas 1996. *The Manual of Low-Slope Roof Systems*, 3rd Ed., McGraw-Hill, New York.

Koontz, J. D. 1987. "A Comparative Study of Dynamic Impact and Static Loading of One-Ply Roofing Assemblies," pp. 23–51 in *Roofing Research and Standards Development*, ASTM STP 959, edited by R. A. Critchell, American Society for Testing and Materials, West Conshohocken, Penn.

Lys, H. P. 1985. "Aging Criteria for PVC Roofing Membranes," pp. 270–74 in *Proceedings, Second International Symposium on Roofing Technology*, National Roofing Contractors Association, Rosemont, Ill.

Marien, H. R. 1982. "The Finishing Touch," *Engineering & Services Quarterly*, Summer, 10–11.

NRCA/SPRI 1990. *Shattering of Aged Unreinforced PVC Roof Membranes*, National Roofing Contractors Association, Rosemont, Ill., with SPRI, Needham, Mass., September.

Paroli, R., T. L. Smith, and B. J. Whelan 1993. "Shattering of Unreinforced Roof Membranes: Problem Phenomenon, Causes and Prevention," pp. 93–107 in *Proceedings, 10th Conference on Roofing Technology*, National Roofing Contractors Association, Rosemont, Ill.

Paroli, R. M., O. Dutt, A. H. Delgado, and H. K. Stenman 1993. "Ranking PVC Roofing Membranes Using Thermal Analysis," *J. Materials in Civil Engineering*, 5(1), (February), 83–95.

Paroli, R. M., O. Dutt, T. L. Smith, and B. J. Whelan 1994. "Enhancement of the Standard for PVC Roof Membrane Material With the Use of Mechanical and Chemical Analysis," pp. 116–22 in *Roofing Research and Standards Development: 3rd Volume*, ASTM STP 1224, edited by T. J. Wallace and W. J. Rossiter, American Society for Testing and Materials, West Conshohocken, Penn.

Patuska, Gerhard 1985. "Roof Coverings Made of PVC Sheetings: The Effect of Plasticizers on Lifetime and Service Performance," pp. 173–76 in *Proceedings, Second International Symposium on Roofing Technology*, National Roofing Contractors Association, Rosemont, Ill.

Rosenfeld, M. J. 1981. *An Evaluation of Poly(Vinyl Chloride) (PVC) Single-Ply Roofing System*, Technical Report M-284/ADA097931, U.S.Army Corps of Engineers, Construction Engineering Research Laboratories, Champaign, Ill., March.

Rosenfeld, M. J. 1984. *Construction of Experimental Poly(Vinyl Chloride) (PVC) Roofing*, Technical Report M-343/ADA145406, U.S.Army Corps of Engineers, Construction Engineering Research Laboratories, Champaign, Ill., April.

Rossiter, W. J., and R. G. Mathey 1978. "Elastomeric Roofing: A Survey," Technical Note 972, National Bureau of Standards (now National Institute of Standards and Technology), July.

Rossiter, W. J., E. Byrd, W. Roberts, and D. Bailey 1995a. "The Applicability of Modern Analytical Techniques to Detection of Changes in Roofing Membrane Materials Brought About by Heat Aging," pp. 242–52 in *Proceedings, IX International Congress, International Waterproofing Association*, Amsterdam, The Netherlands, April 26–28.

Rossiter, W. J., J. J. Lechner, D. M. Bailey, and S. D. Foltz 1995b. *Long-Term Field Test Results for Poly(Vinyl Chloride) (PVC) Roofing*, Technical Report 96/23, U.S. Army Corps of Engineers, Construction Engineering Research

Laboratories, Champaign, Ill., December.

Roodvoets, D. L. 1995. "The Robust Roof," pp. 709–16 in *Proceedings of the Thermal Performance of the Exterior Envelopes of Buildings Conference VI*, Clearwater Beach, Florida, December 4–8, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta.

Smith, T. L. 1996. "High-Wind Performance of Mechanically Attached Single-Ply Roof Systems," *Professional Roofing*, February, 18–22.

KEYWORDS

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