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Factors Affecting the Service Life of Seams of EPDM Roof Membranes

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ABSTRACT

A quarter century ago, a revolution occurred in the U.S. low-sloped roofing industry with the introduction of a number of new membrane products including elastomeric and thermoplastic polymeric membranes and polymer-modified bituminous membranes. Today, these membranes account for over two thirds of the total low-sloped roofing market in the United States. One single-ply membrane, EPDM (ethylene-propylene-diene terpolymer), gained wide acceptance in that it captured about one-third of the total low-sloped roofing market by the mid-1980s. Also by the mid-1980s, however, surveys conducted by the U.S. National Roofing Contractors Association (NRCA) began to indicate that the EPDM seams were failing leading to roof leaks. These seams were fabricated in the field using liquid-applied polymer-based adhesives. Due to the economic importance of EPDM roofing, the high costs associated with leaking roofs and, most importantly, the urging of the contractor segment of the roofing industry, the National Institute of Standards and Technology (NIST) initiated research to elucidate the factors affecting the service life performance of EPDM seams. The majority of this research was conducted under the auspices of an industry-government consortium. This paper presents a short overview of the NIST experimental findings. At the beginning of the research and in collaboration with industry, NIST attempted to identify the most likely application, design, material, and environmental variables affecting seam service life performance. From this list of over two-dozen variables, the contribution that each variable made acting alone or in combination was assessed through statistically designed creep-rupture experiments. Outcomes of these experiments included the identification of the most important variables affecting seam performance and the derivation of a mathematical model for linking field and laboratory seam joint responses. The results of these experiments lead to recommendations for improving the service life performance of seam joints. These recommendations were adopted by industry and contributed significantly to the improved performance of EPDM seams. Today, EPDM seams fabricated with tape adhesives and the service life performance of these tape-bonded seams are routinely acknowledged by industry as being quite satisfactory.

Keywords

Building technology; creep-rupture testing; EPDM roofing; seam adhesion; service life prediction

1 INTRODUCTION

Twenty-five years ago, a revolution occurred in the U.S. roofing industry with the introduction of elastomeric and thermoplastic synthetic single-ply membranes and also polymer-modified bituminous membranes. Of these new products, one single-ply membrane captured over 50 % of this market, and approximately one-third of the total U.S. low-sloped roof market. It still maintains this market share today. This membrane was EPDM (ethylene-propylene-diene terpolymer), and is the subject of this paper.

Like most new material revolutions, the growth of the new roofing membranes was so fast that many products were introduced into the marketplace prior to gaining any substantial service life performance histories. Not unexpectedly, problems in the service life performance of these products were often observed shortly after they were introduced. The percentage of new membrane use and the number and frequency of associated problems with each membrane type were tracked by Project Pinpoint, which is a U.S. National Roofing Contractors Association (NRCA) lead roof survey program launched in 1974 to provide (1) an early-warning procedure for the identification of problems experienced with in-place low-sloped roofing materials, and (2) baseline information on the membrane materials used and how often they were installed [NRCA 1975, Cullen 1989]. Multiple Project Pinpoint reports were published from 1975 to 1992. From these reports, the use of the elastomeric, thermoplastic, and polymer-modified bitumen membrane materials was almost non-existent prior to the mid-1970s, but by the end of the 1980s, they accounted for about 70 % of the low-sloped roofs installed in the United States—a figure that has remained reasonably constant to the present [Cullen 1993]. Another important finding was that the number and frequency of problems with the service life performance of single-ply membranes also increased from their inception in the mid-1970s.

EPDM is a chemically inert rubber, which makes it attractive for outdoor use as a membrane material, because the membrane itself has excellent weathering properties. However, chemical inertness can be a disadvantage when bonding adjacent sheets in the field to form the seams of a waterproofing membrane. As early as the mid-1980s, Project Pinpoint surveys were indicating numerous problems with the seams which, at that time, were formed using liquid polymer-based adhesives [NRCA 1984, Cullen 1989]. Leaking roofs are of national importance due to high costs associated with degradation of the roofing materials and to consequential damages to the building interior and its contents. With this recognition and, most importantly, with the urging of NRCA, NIST initiated research in the mid-1980s to elucidate the factors affecting seam performance and to recommend solutions for improved performance. This paper summarizes some of the main findings and recommendations from those studies. The majority of NIST research activities were conducted collaboratively with industry.

2 PERFORMANCE OF LIQUID-ADHESIVE-BONDED SEAMS

The NIST seam studies were initiated in the mid-1980s using specimens prepared with liquid-applied polychloroprene- and butyl-based adhesives, the primary adhesives available for making EPDM seams at the time. In developing background information for the studies, NIST research staff reviewed the literature and held numerous discussions with individuals knowledgeable regarding the performance of EPDM roofing including manufacturer representatives, contractors, consultants, and adhesive technologists. Based on the information obtained, numerous possible application, design, material, and environmental 'faults' were identified that, acting alone or in combination, were felt to lead to the failure of EPDM seams (Fig. 1). The selection of these factors was largely based on field experience. Specifically, over 85 % of the reported roofing problems were indicated as developing within the first three years after installation of the roof with the majority of these early failures, ≈ 60 %, occurring within

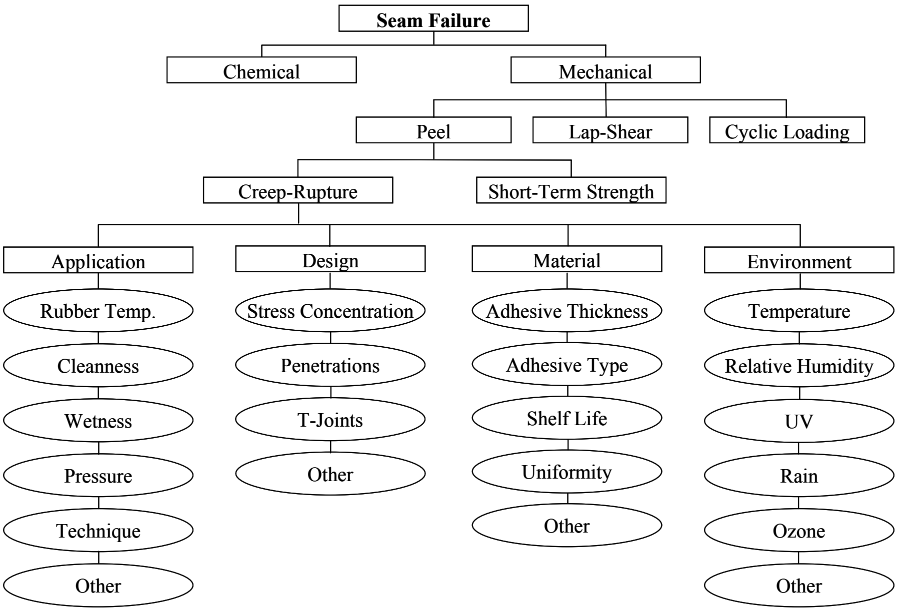

Figure 1. Factors Affecting the Durability of Seams of EPDM Roofing Membranes

the first year after installation [NRCA 1984]. Additionally, the longer the roofing seams appeared to survive without problems, the longer the carefree maintainance of the roof. From these observations, it was concluded that the failure of many EPDM seams was probably not due to the chemical degradation of the seam joint, because the longer a seam joint remained defect free, then the longer its service life. NIST field inspections of EPDM roofing also supported feedback obtained from the roofing community that seam failures were often associated with EPDM roofs that exhibited ripples resulting from the contractors inability to lay the membranes down flush with the roof (Fig. 2). NIST researchers reasoned that such ripples would subject the seams to small peel loads which over time could lead to a creep-rupture failure. Based on this a priori assumption, they developed creep-rupture test protocols suitable to apply a creep-rupture peel stress to seam specimens and observed their times-to-failure [Martin et al. 1990]. The better performing seams had longer times-to-failure. The factors investigated included material parameters such as the adhesive type and its applied thickness, mechanical parameters such as the magnitude and type of load (i.e., peel and shear), environmental parameters such as temperature, moisture and ozone, and application parameters such as the cleanness of the EPDM rubber surface. Consistent with field observations, during these initial studies, it was found that seams were far more resistant to sustaining shear creep-rupture loads than they were to sustaining peel creep-rupture loads. Consequently, the subsequent investigations focused on understanding the peel creep resistance effects of small changes in application, material, and environmental factors.

Martin et al. [1989, 1990] described initial NIST creep-rupture experiments and major findings in a study undertaken to examine the importance and ranking of the following material and application variables on creep resistance and short-term strength: adhesive thickness, cure time, mechanical load, adhesive type, and surface cleanness. From these studies, it was concluded that the greatest effects on creep resistance were due to adhesive thickness, the magnitude of the mechanical load, and the cleanness of the EPDM surface. Figure 3 illustrates the effect of adhesive thickness, wherein it is evident that creep resistance varied exponentially with thickness. This was the first reported instance of the effect of adhesive thickness

Figure 2. Ripples in an EPDM Membrane and Seam

on creep resistance of EPDM seam specimens. Its benefit could not be underestimated since, in practice, some contractors admitted to NIST research staff that they did not always apply adhesives at recommended quantities, if for no other reason than to preserve adhesive, or for the more practical reason of lessening the time necessary for application. Consistent with such admissions, NIST observations from field inspections showed, for example, that the adhesive thickness was often less than EPDM manufacturers' recommendations [Rossiter et al. 1991]. Martin et al.'s [1990] adhesive thickness measurements demonstrated the folly in thinking that there was no adverse effect in applying thin adhesive layers. On the positive side, the findings on peel load and surface cleanness reinforced practices that, in service, peel loads should be kept as low as possible, if not avoided, and that EPDM surfaces should be cleaned as well as possible before adhesive application.

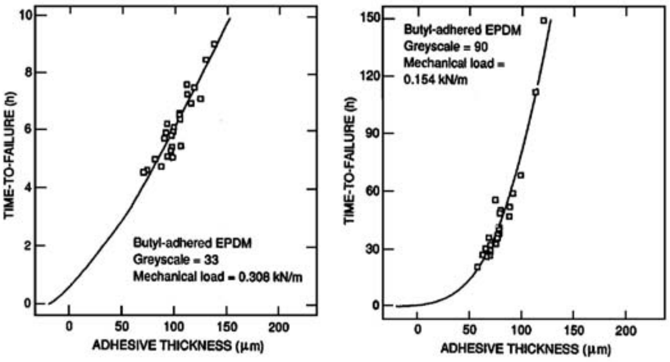

Figure 3. Time-to-Failure versus Adhesive Thickness [from Martin et al. 1990]

Having demonstrated the effects of adhesive thickness and surface cleanness, subsequent experiments were designed to further address the importance of these parameters [Rossiter et al. 1994]. Thus, a creep experiment was conducted using EPDM rubber and butyl-based liquid adhesive. Three variables were included: adhesive thickness (thin and thick), EPDM surface cleanness (well cleaned and particulate contaminated), and type of load (peel and shear). Only a few of the shear specimens failed and the failures were for specimens having thin adhesive and contaminated EPDM. In contrast, the majority of the peel specimens failed. From Fig. 4, the ranking, in decreasing order of creep resistance of the peel specimens was: thick, clean >> thick, contaminated > thin, clean > thin, contaminated where the symbol > signifies "better than" while >> signifies "very much better than." The effect of adhesive thickness was greater than the effect of surface cleanness. Observe also in Fig. 4 that the thick, clean specimens displayed significantly longer mininum times-to-failure, by a factor of at least 100, than did those fabricated using the other three combinations of fabrication conditions. It is noted that, in this and the other NIST experiments described herein, whenever the EPDM surface was well cleaned, the creep-rupture failure mode was cohesive within the adhesive layer.

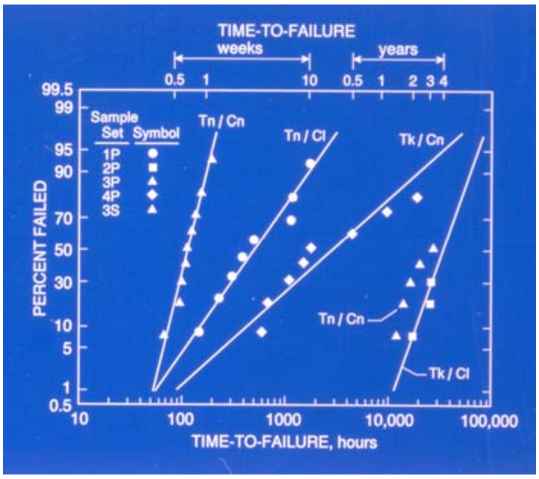

Figure 4. Effect of Adhesive Thickness, Surface Cleanness, and Type of Load on Creep-Rupture Times-to-Failure [from Rossiter et al. 1994]

Overall, the NIST research emphasized that, in practice, significant benefits in service life were accrued when the EPDM surfaces were cleaned and a thick adhesive was applied. The NIST results for adhesive thickness had not been foreseen by anyone with whom discussions were held when the studies on liquid-adhesive seams were initiated and considerable efforts were needed to alter the mindset of many EPDM practitioners. Fortunately, although the relationship between adhesive thickness and seam performance was surprising to many, its implications were taken seriously. For example, in efforts to reach contractors, the NRCA published an article entitled “Is Your Adhesive Layer Thick Enough?” in its monthly trade magazine [Martin et al. 1991].

Finally, it is noted that the importance of adhesive thickness on seam performance was only demonstrated through creep-rupture experiments. Measurements of short-term peel strength showed only a slight effect due to thickness. Consequently, in 1993, ASTM published, based on NIST research, Standard Test Method D5405, “Conducting Time-to-Failure (Creep-Rupture) Tests of Joints Fabricated from Non-bituminous Organic Roof Membrane,” so that the creep-rupture procedure would be available to all having interest in elucidating factors affecting seam performance.

3 PERFORMANCE OF TAPE-BONDED SEAMS

In the early 1990s, as NIST was completing its studies on liquid adhesives, the EPDM roofing manufacturers introduced a new generation of adhesives based on preformed butyl tapes. Many roofing contractors and other practitioners, due to inherent problems with accepting a new product without any tangible field performance data, received the introduction of tape adhesives with little enthusiasm. On the other hand, proponents believed that tape adhesives had advantages over liquid adhesives such as enhanced seam performance, product uniformity, installation robustness, lessened environmental impact because they were solvent-free, and lower seam fabrication costs. In 1994, the EPDM industry requested that NIST establish an industry-government consortium to gain an understanding of the service life performance of tape-bonded EPDM seams [Rossiter et al. 1995]. The original consortium was comprised of three EPDM membrane material manufacturers, two tape adhesive manufacturers, two roofing industry associations, and the U.S. Army Construction Engineering Research Laboratories (CERL). The objectives of the consortium were to (1) compare the creep-rupture performance of tape-bonded and liquid-adhesive-bonded seams of EPDM membranes, and (2) recommend a test protocol for evaluating creep-rupture performance of such seams. The consortium experimental program was designed in three phases. The major findings are summarized in the following paragraphs. For complete details on the experimental procedures and methods of analyses, the reader is referred to the original references.

3.1 Phase I — Effect of Load on Peel Creep

In Phase I, the creep-rupture response of tape-bonded and liquid-adhesive-bonded seam specimens was determined as a function of peel load [Rossiter et al. 1996]. Specimens were fabricated using two commercial tape systems (i.e., tape and primer) and a butyl-based liquid adhesive applied to well-cleaned EPDM rubber. The results are summarized in Fig. 5, which is a plot of mean time-to-failure (TTF) as a function of load. The plot characters represent the mean data points; whereas the curves represent the fit of the data to the model:

$$\ln(TTF) = b_0 + b_1 A\ Load + b_2 A \exp(b_3 A\ Load).$$

In all cases, the mean time-to-failure data points fall on or are close to the fitted curves. It is evident in Fig. 5 that the relationship between time-to-failure and load is relatively linear at the higher loads and nonlinear at lower loads. Note that no data points are included in this figure for tests conducted below 5 N, because no specimen failures were observed after more than 16 800 h (about 23 months) of testing at the lowest load of ≈ 3 N. The major conclusion was that the tape-bonded specimens had times-to-failure that

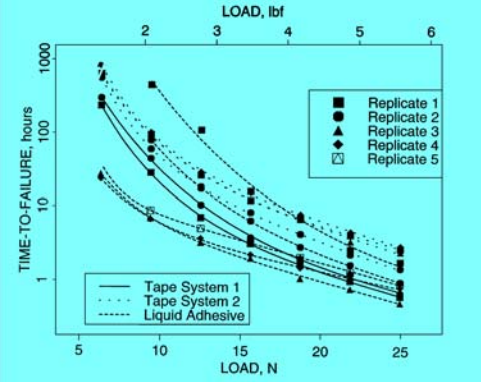

Figure 5. Time-to-Failure Versus Load for Tape-Bonded and Liquid-Adhesive-Bonded Seams [from Rossiter et al. 1996]

were in most cases comparable to, or greater than, those of the liquid-adhesive-bonded specimens. In addition, the tape-bonded specimens provided time-to-failure results that were reproducible between replicate sets. This reproducibility may have been associated with the tapes being factory-made (i.e., pre-formed) products and not subject to some of the non-controllable application variables associated with the liquid-applied adhesives. Observe in Fig. 5 that the liquid-adhesive-bonded sample sets were less reproducible than the two tape systems, particularly at the low loads (e.g., 12.5 N). A consequence of this wide variability was that, under certain conditions, the liquid adhesive provided seam sample sets which displayed substantially longer creep lifetimes than either other liquid-adhesive-bonded sample sets or tape-bonded sample sets. However, the conditions that produced the relatively long-lived liquid-adhesive specimens were not known and not reproducible.

3.2 Phase II — Effect of Material and Application Parameters on Peel Creep

The Phase II research was performed to investigate the effects of material and application factors on the peel creep-rupture response of tape-bonded seam specimens [Rossiter et al. 1997]. The specimens were prepared using the two commercial tape systems from Phase I. Thus, two material factors (tape system and thickness) and five application factors (EPDM surface condition, primer, application temperature, application pressure, and time-at-application-temperature) were examined in a two-level statistically designed experiment. For each parameter, the levels were chosen far enough apart so that the range of practical importance was generally covered. Some tapes had thicknesses typical of those commercially available at the time of the study, and were designated as having ‘standard’ thickness. The thicknesses of 'standard' and thin tapes (which were experimental products for the study) were approximately 0.9 mm and 0.6 mm, respectively. Specimens were prepared either primed or unprimed using EPDM that was either cleaned or contaminated. Application temperatures were low, 5 °C, or high, 60 °C, and application pressures were low, 0.2 MPa, or high, 2 MPa. The time at which the specimens remained at the application temperature was short, about 24 h, or long, 672 h to 960 h. A full factorial design was beyond the scope of the Phase II study, so a half-fraction of the full factorial design was chosen. This design included the four combinations of material factors, and 16 of the 32 possible combinations of the application factors. The same 16 combinations of the application factors were assigned to each of four combinations of the material factors. The main conclusions from the Phase II investigations included:

- Primed, clean EPDM provided the longest times-to-failure. This result, although not unexpected, emphasized to contractors that proper application is a critical parameter affecting tape-bonded seam performance.
- Primed, clean EPDM and 'standard' thickness tape afforded times-to-failure that were greater than the minimum mean times-to-failure of well prepared liquid-adhesive-bonded specimens in the Phase I investigations.
- The application temperatures and application pressures used in the investigation did not affect the times-to-failure of sample sets prepared with primed, clean EPDM that had long times-to-failure. This finding was noteworthy, because application temperatures and manual application of pressure during seam fabrication are impossible to control in practice.
- 'Standard' thickness tape provided significantly longer times-to-failure than thinner tape. This finding was comparable to the adhesive thickness effect found for liquid-adhesive seams [Martin et al. 1990, Rossiter et al. 1994], and provided evidence that seam time-to-failure could be compromised if tapes (having comparable chemical formulations) were made commercially available at thicknesses less than those of the ‘standard’ thickness available at the time of the study.

3.3 Phase III — Effect of Exposure and Shear Load on Creep Response

In Phase III, four tasks investigated the effects of: (I) elevated test temperatures while being subjected to a peel creep-rupture load, (II) elevated temperature exposure prior to being subjected to a peel creep-rupture load, (III) exposure to two industry-developed aging protocols, and (IV) preparation of specimens at cold temperatures prior to peel creep-rupture loading. An additional task (V) examined shear testing [Rossiter et al. 1998]. Specimens were prepared as in Phases I and II using the two commercial tape systems (i.e., tape and primer) and one liquid adhesive applied to well-cleaned EPDM rubber. For each task, comparisons of the creep-rupture responses of tape-bonded and liquid-adhesive-bonded samples were made. Main conclusions of this phase of the research included:

- As the temperature and creep-rupture peel load increased, the times-to-failure of the three adhesive systems decreased. For all treatments, the tape-bonded sample sets had longer mean peel times-to-failure than did the liquid-adhesive-bonded sample sets.
- When peel creep-rupture specimens were exposed to elevated temperatures before loading, times-to-failure of liquid-adhesive-bonded samples were either unaffected or became longer versus the times-to-failure of control specimens (i.e., not temperature exposed). In comparison, peel times-to-failure of one tape-bonded system increased, and that of the other tape-bonded system became shorter (versus the controls) or were unaffected. In cases where the tape-bonded specimen times-to-failure became shorter, they were generally comparable to those for the liquid-adhesive bonded specimens.
- Many shear creep-rupture tests, particularly those at room temperature, produced few failures within the allotted test time. At 70 °C and loads of 24.9 kN/m and 28.0 kN/m, both tape systems had shorter shear-creep lifetimes than the liquid adhesive system. The practical significance of these results is questionable, because the thermal expansion coefficient of EPDM is usually much greater than that of other roofing system materials. The EPDM would tend to generate ripples as opposed to being stressed in shear at high temperatures.

3.4 Overall Results of the Tape-Adhesive Studies

Consistently throughout the consortium study on tape-bonded seams, specimen sets fabricated using either one of two tape-adhesive systems and cleaned, primed EPDM had mean peel times-to-failure that were generally comparable to, if not greater than, those of liquid-adhesive-bonded specimen sets. Moreover, although some laboratory exposures resulted in shorter peel times-to-failure for some tape-bonded seams versus the controls, the resultant times-to-failure were yet comparable to values measured for some field-sampled tape-bonded seams that had performed well in service. EPDM practitioners were enthusiastic about the findings and considered that the consortium study played a key role in accelerating the acceptance of tape-bonded seams in the United States. In 1998, the NRCA marked the study conclusion with the acclamation that “laboratory and field studies confirm the viability of tape-bonded seams” [Smith 1998]. Additionally, the second consortium objective on development of a test protocol for evaluating creep-rupture performance of tape-bonded seams was successfully met. Specifically, the results provided the technical basis of ASTM Standard Practice D6383, “Time-to-Failure (Creep-Rupture) of Adhesive Joints Fabricated from EPDM Roof Membrane Material.” Tape adhesives are now well accepted by EPDM practitioners to the extent that they are the cornerstone adhesives for EPDM seam fabrication.

4 FINAL COMMENTARY

Today in the United States, EPDM membranes systems are routinely installed on low-sloped roofs. They provide architects, engineers, contractors, building owners, and others a viable choice among the many low-sloped systems available to the U.S. roofing industry. The issue of satisfactory seam performance is no longer topical. Advances in adhesive technology by EPDM manufacturers and proper seam application by roofing contractors have set aside the issue. In the United States, creep-rupture testing has become a well-accepted method for generating service life data on the performance of seams of EPDM membranes. Creep-rupture testing, particularly in peel, should be an integral part of any methodology that evaluates the service life of EPDM seams.

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