Roofing Research and Standards Development

Second Volume

Wallace/Rossiter editors

ASTM STP 1088

STP 1088

Roofing Research and Standards Development: 2nd Volume

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ASTM
1916 Race Street
Philadelphia, Pa 19103

Library of Congress Catalogue Card Number: 87–31938
ASTM Publication Code Number (PCN): 04-010880-57
ISBN: 0-8031-1393-5
ISSN: 1050-8104

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The quality of the papers in this publication reflects not only the obvious efforts of the authors and the technical editor(s), but also the work of these peer reviewers. The ASTM Committee on Publications acknowledges with appreciation their dedication and contribution of time and effort on behalf of ASTM.

Printed in Chelsea, MI
November 1990

Foreword

The papers in this publication, *Roofing Research and Standards Development: 2nd Volume,* were presented at a symposium held in San Francisco, California, 17 June 1990. The symposium was sponsored by ASTM Committee D08 on Roofing, Waterproofing, and Bituminous Materials. Thomas J. Wallace, U.S. Navy, and Walter J. Rossiter, Jr., National Institute of Standards and Technology, served as symposium cochairmen and are editors of this publication.

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BITUMINOUS ROOFING SYSTEMS

OVERVIEW

The revolution that has occurred in the U.S. roofing industry over the last decade is well known to all. Many roof systems which incorporate elastomeric, thermoplastic, and polymer-modified membranes were unheard of in the early 1970s, but are commonly used today. Improvements in their chemistry and production technology have enhanced the performance of these materials and made them economically competitive. Further, the use of glass- and polyester-based fabrics has essentially replaced the traditional reinforcements for built-up roofing systems. With the arrival of the new membrane systems, innovative methods of membrane securement such as ballasting and mechanical attachment were brought into the industry. A major result of the changes in roofing practices was increasing pressure on ASTM Committee D 08 on Roofing, Waterproofing and Bituminous Materials to develop standards to assist in the proper selection, use, and application of these systems. Committee D 08 has responded well. Many task groups have been formed and are diligently working toward development on the needed standards.

The Proceedings of two symposia describing the changes that have occurred and the needs for research to support development of standards were published in the 1980s -- Single-Ply Roofing Technology, ASTM STP 790 (1982), edited by W.H. Gumpertz, and Roofing Research and Standards Development, ASTM STP 959 (1987), edited by R.A. Critchell. But the work of Committee D 08 is far from finished, particularly in the area of conducting research to support the standards development process.

The members of D 08 firmly believe in the importance of having a strong technical basis for their Committee's standards. The availability of data can help accelerate the standards development process, since decisions can be made on fact and not opinion. In 1987, Subcommittee D 08.21 on Research Needs for Roofing and Waterproofing was formed to: (1) provide information on ongoing research, (2) identify research needed in standards development, and (3) disseminate research results through activities such as workshops and symposia. This symposium represents the first fruits of the Subcommittee's efforts to foster research in the support of standards. It illustrates the commitment made by D 08 to the improvement of roofing technology.

As in the past, this publication is dedicated to the members of ASTM Committee D 08 who give unselfishly of their time and energy to improve the performance of

roofs. The editors express their sincere thanks and appreciation to those many individuals who participated in the organization and conduct of the symposium. R.A. Alumbaugh, C.G. Cash, E.F. Humm, D.F. Jennings, C.F. Mullen, W.T. Rubel, T.L. Smith, and S.W. Warshaw were members of the Steering Committee. D.E. Richards was a session chairperson. Dorothy Savini, ASTM, provided for the symposium arrangements. Barbara Stafford, Therese Pravitz, Kathy Greene, and other ASTM staff members directed the review and publication of the papers. Finally, special thanks are given to the authors and reviewers of the papers without whose efforts the symposium would not have been possible.

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Elastomeric and Thermoplastic Roofing Systems

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Characterization of Lap Seam Strength for In-place and Laboratory Prepared EPDM Roof Membranes

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REFERENCE: Hodges, Christopher P.,"**Characterization of Lap Seam Strength for In-place and Laboratory Prepared EPDM Roof Membranes,"** Roofing Research and Standards Development: 2nd Volume, ASTM STP 1088, Thomas J. Wallace and Walter J. Rossiter, Eds., American Society for Testing and Materials, Philadelphia, 1990.

ABSTRACT: A series of T-Peel lap seam adhesion tests were conducted on various EPDM roof membrane samples in order to characterize the typical expected seam strength in laboratory prepared samples, and in samples taken from new and in-service roofs. The program included constructing lap seams in the laboratory using four commercially available EPDM roof membranes and their proprietary adhesives and seaming techniques. In addition, two sets of seams were made and tested in the laboratory without the benefit of cleaning the splice area of the rubber. T-peel testing was also conducted on samples taken from two roofs that were approximately 6 months and 5 years in age. Three other sets of contractor prepared field seams were obtained during on-site roof construction and tested in T-peel. The objective of the study was to provide some reference data relative to seam strength developed in the laboratory versus that which is typically achieved in the field.

KEY WORDS: EPDM, T-peel test, lap seam, adhesion, strength development, single-ply, field seams, butyl adhesive, neoprene adhesive, in-service.

In the roofing industry, the last 25 years have brought dramatic changes in the use of new materials and assemblies. A market that was once dominated by built-up roofing is now inundated with new products. One material, first introduced in the 1960's, has dominated the single-ply market for a number of years. EPDM (ethylene propylene diene terpolymer) accounts for over half of the single ply market.

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It has generally been accepted through a number of marketing and research efforts that, for single-ply roofs, the field seam is the most frequently reported problem area [1]. The primary method that has been developed to characterize the seam strength is the T-peel test (ASTM D 1876). Research has shown the T-peel test to be sensitive to typical application parameters [2,3,4].

Although the seam has been identified as the leading problem in single-ply roofing, we still do not fully understand and do not know the strength required of a single-ply membrane field seam under actual service conditions. A significant amount of data is available regarding single-ply membrane material properties, however, there is an overall lack of data about the minimum levels of mechanical properties required of a roof membrane in-service.

Through other research, and the efforts of this study, we begin to understand the typical expected "as-built" strength of an EPDM lap in T-peel. It would be inappropriate to assume that the failure mechanism of all in-service seams would necessarily be in peel. Due to imposed loads, a roof membrane may be subjected to combinations of shear and peel forces. Until such time as a test is developed which more accurately duplicates the typical failure mechanism, the T-peel test remains one of the most sensitive test methods to parameters such as seam cleanliness, application temperature, application rate (adhesive thickness), seam open time and other factors. In contrast to other construction materials, which typically measure their strength with significantly high numbers, the peel strength of an EPDM seam is relatively low, typically measured to be less than 1.75 kN/m (less than 10 pounds per inch of seam).

This study presents results of over 300 T-peel tests conducted on commercially available EPDM membranes and their associated adhesive products. The focus of the study was to provide further data on the characterization of seam strength values under laboratory and field conditions. The laboratory portion of the study was conducted on roofing materials that were purchased from local roofing suppliers, or were supplied by roofing contractors during a roof construction project. The purpose of this was to use actual "off the shelf" products to gain practical knowledge about how these products perform. The study was divided into three areas:

1. Analysis of properly prepared laboratory seams to characterize the development of strength at early ages, and establish some expected strength values.

2. Analysis of laboratory prepared seams which were made without using the recommended preparation and cleaning process. The purpose of this was an attempt at duplicating what might occur in the field if the applicator were to omit one of the recommended steps in the seam cleaning process.

3. Analysis of some lap seams that were obtained from roofing projects. This included testing of contractor - prepared lap seams taken from roofs during the

construction process, and testing lap seams that had been in-service from a few months to over five years.

The results of these tests are presented in this paper, along with a discussion of the methodology for testing and the significance of the tests.

Sample Preparation and Specimen Testing

Four sets of EPDM seam samples were fabricated in the laboratory in accordance with the manufacturers' instructions (Table 1). Four different EPDM manufacturers products were represented. Set 1C was fabricated using a 1.5 mm (60 mil) thick EPDM sheet and butyl based adhesive. Sets 2C and 3C were fabricated with 1.1 mm thick (45 mil) EPDM sheets and butyl based adhesives. Set 4C was a 1.1 mm thick (45 mil) EPDM sheet with a neoprene based adhesive.

To examine strength gain, the four sets were tested in T-peel at ages of 2 hours, 4 hours, 8 hours, 1 day, 3 days, and 7 days. Additional tests were conducted on sets 1C and 2C at 21 days. Preparation of the samples was performed under laboratory conditions of 23 ± 2° C (73 ± 3° F) and 40 to 50 percent relative humidity. No specific attempts were made to control application rate of the adhesive in this study. Rollers were used to apply the adhesive and these were purchased from roofing suppliers and duplicated typical application practices in the area at the time of the study. Adhesive thickness was measured in each of the test samples by measuring the overall thickness of the lap and subtracting the measured thickness of the two overlapped sheets.

Since many precautions have been stated about the proper mixing of the adhesive prior to application [5], the adhesives were extensively stirred. Procedures for preparation of the splice area varied between manufacturers. Of the manufacturers' products tested, some required the use of a proprietary solvent for cleaning the splice area of the rubber, or use of a proprietary primer after solvent cleaning. Others only required cleaning the splice area with heptane, hexane, or unleaded gasoline. In these cases, unleaded gasoline was used to clean the splice area.

T-peel testing was conducted in general accordance with ASTM D 1876 [6]. The samples were prepared for T-peel testing by cutting 25 mm (1 in.) wide strips from the laboratory prepared seam in a direction perpendicular to the seam length. One end of the seam was peeled back about 25 mm (1 in.), and the opened portions of the seam were placed in the grips of a tensile testing machine. The load was then applied by pulling the lap in opposite directions, perpendicular to the adhesive line. The force required to separate the two layers of EPDM was measured and recorded continuously throughout the test. Since the force required to separate the sample varies slightly over the width of the seam, the force is averaged over the test length to obtain the average T-peel force per 25 mm (1 in.) of seam width.

Specific deviations from ASTM D 1876 were that the machine crosshead speed was 50 mm (2 in.) per minute, and the length of seam over which the T-peel strength was measured was about 50 to 76 mm (2 to 3 in.). This test speed has been widely used for the testing of EPDM seams. The length of the test area was less than specified in D 1876 because of limitations of the test apparatus.

Results and Discussion

Laboratory Prepared Specimens - Cleaned

Table 1 provides a listing of the EPDM sheet thickness, the adhesive type, the average adhesive thickness, and the T-peel test data for the laboratory prepared cleaned samples. Table 1 also lists the type of seam preparation normally prescribed by the manufacturer. The strength values shown in Table 1 represents an average of five peel tests conducted on strips cut from the laboratory test sample. The coefficient of variation for all of the laboratory prepared, cleaned samples was less than 20 percent. This data agreed with the precision stated in a previous study [4].

TABLE 1 -- Summary of Laboratory T-Peel Results - Cleaned

MEMBRANE DATA				
Set Number:	1C	2C	3C	4C
Sheet Thickness mm:	1.5	1.1	1.1	1.1
(mils):	(60)	(45)	(45)	(45)
Adhesive Type:	Butyl	Butyl	Butyl	Neoprene
Adhesive Thickness mm:	0.14	0.21	0.26	0.06
(mils):	(5.7)	(8.3)	(10.1)	(2.3)
Splice Preparation:	Splice Cleaner	Unleaded Gas + Primer	Unleaded Gas	Unleaded Gas + Primer
AGE	T-PEEL STRENGTH kN/m (lbf/in.)			
2 Hours	0.25 (1.40)	0.25 (1.40)	0.29 (1.66)	0.48 (2.72)
4 Hours	0.50 (2.86)	0.23 (1.34)	0.46 (2.60)	0.56 (3.18)
8 Hours	0.61 (3.48)	0.29 (1.64)	0.65 (3.74)	0.59 (3.38)
1 Day	0.78 (4.44)	0.50 (2.86)	0.89 (5.10)	0.52 (2.94)
3 Days	0.76 (4.34)	0.63 (3.58)	0.78 (4.44)	0.48 (2.76)
7 Days	0.94 (5.38)	0.70 (4.00)	1.16 (6.64)	0.64 (3.68)
21 Days	0.96 (5.50)	0.70 (4.02)	...	...

Best fit curves were plotted to describe the strength gain of sample sets 1C, 2C, and 3C (butyl based adhesives) and are shown in Figure 1. The strength development of sample set 4C (neoprene based adhesive) is represented in Figure 2. The curves were plotted using curve fitting computer software which described the best fit as a log function.

FIGURE 1--Best-Fit Strength Development Curve for Sets 1C, 2C, and 3C

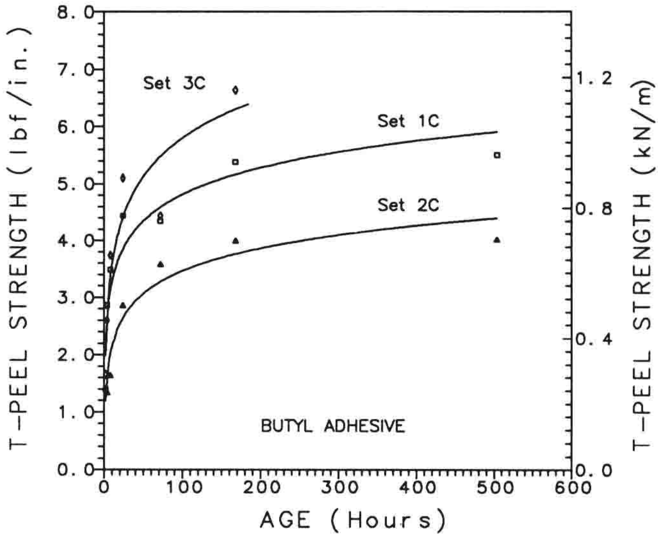
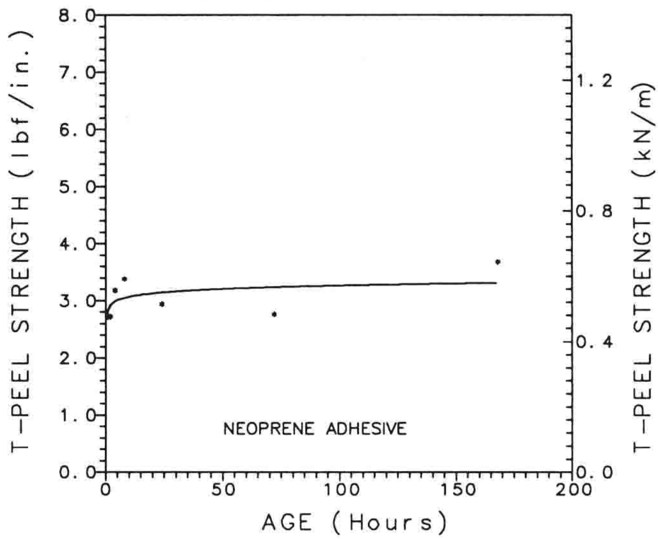


FIGURE 2--Best-Fit Strength Development Curve for Set 4C



For the butyl based adhesives, a comparison of the T-peel strengths at 3 days and 7 days to that at 21 days (sets 2C and 3C), indicates that about 75 percent of the strength gain occurred within 3 days, and over 85 percent of the strength gain occurred within 7 days. This represents peel strengths of about 0.6 to 0.9 kN/m (3.3 to 5.5 lbf/in.) in 3 days, and about 0.7 to 1.1 kN/m (3.8 to 6.4 lbf/in.) in 7 days. The ultimate strength (considered to be about 21 days for the purposes of this study), was on the order of 0.8 to over 1.0 kN/m (4.4 to over 6 lbf/in.). The strength of the butyl based adhesive at 0.8 kN/m (4.4 lbf/in.) is lower than that reported in previous studies for laboratory cleaned samples.

The mode of failure, whether cohesive, adhesive, or a mixture of the two, was observed during peel testing. Cohesive failure occurred when separation of the EPDM strips occurred in the adhesive itself, and adhesive was observed to be still adhered to both of the sheet surfaces. Adhesive failure occurred when the adhesive separated cleanly from one of the sheet surfaces. In some sample sets, the failure mode was observed to be a combination of cohesive and adhesive failure. Table 2 lists the failure mode for each of the sample sets at each test age. When the mode was mixed, the primary failure type is indicated in the table.

TABLE 2 -- Primary Failure Mode for Laboratory Samples - Cleaned

	FAILURE MODE			
Age	Set 1C	Set 2C	Set 3C	Set 4C
2 Hours	Cohesive	Cohesive	Cohesive	Adhesive
4 Hours	Cohesive	Cohesive	Cohesive	Adhesive
8 Hours	Cohesive	Cohesive	Cohesive	Adhesive
1 Day	Cohesive	Adhesive	Cohesive	Adhesive
3 Days	Cohesive	Adhesive	Adhesive	Adhesive
7 Days	Cohesive	Adhesive	Adhesive	Adhesive
21 Days	Cohesive	Adhesive	...	...

The primary mode of failure for the butyl based adhesives (Sets 1C, 2C, and 3C) was cohesive, at least up to about one to three days. At that point, Sets 2C and 3C failed adhesively. As the T-peel strength reached about the 0.5 to 0.8 kN/m (2.9 to 4.6 lbf/in.) level, the failure mode changed from cohesive to adhesive. This was unexpected. A well bonded seam would be expected to fail cohesively at later ages, such as in Set 1C. In spite of cleaning the rubber sheet, the failure occurred due to an interfacial effect. This was also observed in a study by Rossiter et al [7]. In this study, even cleaned specimens failed adhesively at later ages (7 to 14 days) at strengths of about 0.7 to 1.0 kN/m (4 to 6 lbf/in.). The combination of lower than expected strength (Set 2C), and adhesive failure implies that weakest part of the seam was at the interface of the rubber and the adhesive.

With regard to the neoprene adhesive, its initial strength is greater than that of the butyl based adhesives (Table 1). However, the point at which the neoprene based adhesive reached 85 percent of its 7-day strength was about 4 to 8 hours. The ultimate strength of the neoprene based adhesive (considered to be at about 7 days for the purposes of this study), was about 0.6 kN/m (3.3 lbf/in.). Based on interpolation of the best-fit curve, the neoprene based adhesive peel strength was only about 50 to 75 percent of that achieved using a butyl based adhesive. The neoprene adhesive had much higher initial strength than the butyl, however, little increase in strength was observed after about 8 hours. For the neoprene based adhesive, the failure mode was adhesive in all cases.

<u>Laboratory Prepared Lap Seams - Uncleaned</u>

The materials used for preparing the uncleaned specimens were from the same manufacturers and using the same sheet thicknesses as in sets 1C and 2C. In lieu of the recommended cleaning process, the splice area of the rubber sheet was simply wiped with a clean dry cloth to remove any gross particulate contamination. Following this minimal preparation, the adhesive was applied and the seams constructed in accordance with the manufacturers' recommendations.

The uncleaned lap seams were tested at the ages of 4 hours, 8 hours, one day, 3 days, and 7 days. Table 3 provides a listing of the sheet thickness, adhesive type, and a summary of the T-peel test data. The strength values shown in Table 3 represents an average of five peel tests conducted on strips cut from the laboratory test sample. The coefficient of variation for all of the laboratory prepared, uncleaned samples was less than 20 percent. Table 4 shows the primary failure mode for each set of test strips at each test age.