NISTIR 89-4155

REPORT OF ROOF INSPECTION: CHARACTERIZATION OF NEWLY-FABRICATED ADHESIVE-BONDED SEAMS AT AN ARMY FACILITY

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Prepared with the support of:
U.S. Army Engineer District, Baltimore
P.O. Box 1715
Baltimore, MD 21203-1715

October 1989

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ABSTRACT

This investigation was a limited study of seams in an EPDM rubber membrane of the roof of the new "Wheeled Vehicle Facility" Building at Aberdeen Proving Ground, Maryland. The study was initiated at the request of the Corps of Engineers (CoE) to provide data that could contribute to a data base on the characterization of newly-prepared field seams. The investigation was beneficial to the National Institute of Standards and Technology (NIST) because it complemented laboratory research on test methods for evaluating seams of vulcanized rubber roof membranes.

Field seam specimens were taken from the roof and analyzed for peel strength and surface condition of the rubber. At the time of the inspection, the application of the EPDM rubber membrane was considered by CoE personnel to be proceeding satisfactorily. Peel tests indicated that the field seams had low bond strengths in comparison to the strengths achieved by cleaned control specimens prepared on the roof using the same procedure and the same adhesive/rubber system. Both the field specimens and cleaned controls, for the most part, failed cohesively during peel testing. Unlike the cleaned controls, the adhesive layers of the delaminated field seams were found to contain numerous void areas. These voids may contribute to low strength of the adhesive layer, because they represent areas of little or no bond. In addition, because the control seams were cured primarily under laboratory conditions, a question was raised whether the rates of adhesive cure in the field and laboratory were different. Scanning electron microscopy (SEM) analysis of uncleaned control specimens and also small areas of the field specimens that failed adhesively during peel testing showed platelet particles, typical of the release agent, present on the surfaces of both the rubber strip and the corresponding adhesive layer. This finding indicated that, in these cases, some peeling during testing occurred through the layer of release agent on the rubber surface.

Key words: adhesive-bonding, bond strength, EPDM rubber, field inspection, low-sloped roofing, membranes, roofs, seams, scanning electron microscopy (SEM) analysis, surface condition

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1. INTRODUCTION

The use of EPDM rubber membranes for waterproofing low-sloped roofs of industrial- and commercial-type buildings at U.S. Army installations has increased significantly over the last ten years. In general, the growth in use has reflected that which has occurred in the private sector of the building industry in the United States [1,2]. From a recent survey of the performance of EPDM rubber roofing at Army installations across the United States, it was roughly estimated that the Army has in place more than 800 buildings with these roofing systems [3].

This survey found that the performance of the EPDM rubber roofing at Army facilities has been generally satisfactory, although not problem-free [3]. The majority of the few problems reported in the survey concerned seams. However, most of the seam problems were found to be isolated. For example, one facility engineer indicated that, on his base, one building out of 24 having EPDM rubber membranes had leaks through seams [3].

The finding in the Army survey that unsatisfactory seam performance was the performance factor of most concern with EPDM systems was consistent with the general experience of the roofing industry regarding adhesive-bonded seams in EPDM rubber membranes [4,5,6]. Defective seams have been the most often reported problem for single-ply roofing systems in "Project Pinpoint" surveys conducted by the National Roofing Contractors Association [7,8].

Because of the general industry concerns regarding seams coupled with the increased use of EPDM rubber roofing at Army installations, the U.S. Army Corps of Engineers (COE) considered it beneficial to obtain data on field performance. COE facility engineering staff members have recognized the potential of using roofs under their responsibility to characterize newly fabricated seams as well as those which have been in service for some period of time. Little data have been published on the characteristics of seams sampled from roofs. The availability of such data would help further the understanding of the factors affecting seam performance, and could assist in developing guidelines for assuring the quality of seams to perform satisfactorily over the service life of the membrane.

Data generated in the field studies for the Corps of Engineers could support the development of a quality assurance (QA) methodology for newly-fabricated seams. In previous studies [9,10] at the National Institute of Standards and Technology[1] (NIST), it was proposed that a T-peel test of bond strength offered promise as a QA indicator that a seam was properly prepared. For example, T-peel specimens fabricated using cleaned and uncleaned rubber surfaces had significantly different bond strengths 6 hours (and beyond) after formation [10]. Moreover, temperature during bond formation had little effect on the strength for the cleaned and uncleaned sets of specimens. However, the NIST authors indicated that considerable data from the field are needed before a quality assurance methodology, based on peel strength, could be put into practice.

This report presents the results of a limited field study initiated at the request of the U.S. Army Corps of Engineers (COE), Baltimore District. The request centered on the roofing of the new "Wheeled Vehicle Facility" Building at Aberdeen Proving Ground, Maryland. COE personnel asked that NIST research staff inspect the roofing and conduct tests of seams sampled from the site. The test results were intended to provide data that could contribute to a data base on the characterization of newly prepared field seams.

The field inspection was conducted during the fall of 1988. The building was under construction and a mechanically attached EPDM system was being installed. Samples were cut from four seams of the membrane and two seam specimens were prepared on site by a roof mechanic as controls.

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[1]formerly the National Bureau of Standards (NBS).

The study was beneficial to NIST because it provided field data on seams in service to complement laboratory research on test methods for evaluating seams in vulcanized rubber roof membranes. It provided an opportunity to obtain data on seams shortly after their fabrication in the field. The development of field data on elastomeric and thermoplastic membrane materials was considered to be a key roof industry need by the participants of the Round Table Seminar on "Roofing Research: The Challenge and the Opportunity" [11].

2. THE FIELD INSPECTION

The inspection of the roofing was conducted on 30 November 1988. The roof deck was totally in place with about 75 percent of the insulation and membrane installed. Where the roof membrane and insulation were installed, the system was watertight. At those locations, flashings at the perimeter and at penetrations were in place and waterstops to prevent water from entering the system between the exposed deck and installed roofing had been installed.

2.1 Roof Construction

The roof construction was as follows:

- deck -- fluted steel.
- insulation -- two layers of 2 in (50 mm) thick polyisocyanurate boards.
- membrane -- a single-ply of reinforced EPDM rubber sheet, nominal 0.060 in (1.5 mm) thick. The reinforcement was cross-hatched, with the individual strands being about 0.12 in (3 mm) apart. The reinforcement produced a slight, yet noticeable, cross-hatched pattern of depressions in the surface of the rubber. The surface of the rubber contained a talc-like release agent that had been applied in the factory.
- attachment -- mechanical securement of the membrane and insulation boards using screw fasteners placed in the membrane seams.
- seams -- field seams were prepared by cleaning (washing) the rubber sheets at the overlap areas with a black, proprietary, hydrocarbon-based solvent. After cleaning, a proprietary butyl-based contact adhesive was applied to the rubber surface. Before seam formation, a bead of silicone-based sealant was placed on the adhesive in the center of the lap area, parallel to the seam edge. (Note: The sections of the test specimens containing the bead of sealant were not included in subsequent tests.)

2.2 Notes from the Inspection Regarding the Seams

When COE engineering staff made the request to NIST to inspect the roofing, it was commented that the roof construction was proceeding routinely. Observations made during the inspection were consistent with those comments. Visual inspection of the installed roofing showed nothing out-of-the-ordinary. Most important, the seams in the EPDM rubber membrane appeared to be tight and neatly prepared. In general, the job site on the roof was clean without debris present.

2.3 Seam Specimens

Two sets of duplicate seam specimens were cut from the roof membrane. The age of the first set at the time of sampling was 9 days, while that of the second set was 38 days. These specimens were returned to the NIST laboratories for measurement of T-peel strength, and visual assessment and scanning electron microscopy (SEM) analysis of surface condition after delamination. These specimens are referred to as "field seams."

Besides sampling specimens from the in-place seams during the inspection, two additional specimens, about 24 x 8 in (600 x 200 mm), were prepared on the roof by a mechanic using the rubber and adhesive system from which the existing membrane was being constructed. The first was fabricated from rubber sheets having surfaces washed according to prescribed techniques using the proprietary cleaning solution of the manufacturer. The cleaning technique was the same as that used to prepared the field seams of the membrane. The second specimen was made from rubber sheets without cleaning of their surfaces.

For both the cleaned and uncleaned specimens, the contact adhesive was applied to the rubber surfaces using a brush, and the adhesive bonds were formed in the same manner used to fabricate the seams of the membrane. The two specimens made during the inspection were designated as controls for characterizing the seam strength attained when the rubber surfaces were either cleaned or uncleaned. In the present report, the two specimens are referred to as "cleaned controls" or "uncleaned controls," respectively.

Immediately after fabrication, the control specimens were brought to a heated construction trailer (temperature about 70 °F or 21 °C). Tests of the bond strength of these specimens were made (see Section 2.3.1 below) in the trailer at two and four hours

(± 10 minutes) after bond formation using a portable T-peel test device. A set of tests were subsequently made in the evening at the home of one NIST researcher, and the remainder were conducted at later times in the NIST laboratory using the portable test device.

2.3.1 T-peel Tests. T-peel tests were conducted according to the procedure described in ASTM D 1876, "Standard Test Method for Peel Resistance of Adhesives (T-Peel Test)" [12] with two exceptions. First, the rate of peel was 2 in/min (50 mm/min), and second, the length of delaminated bond was about 4 in (100 mm). Laboratory tests were conducted using a universal testing machine, or the portable T-peel apparatus, as mentioned above. In both cases, the test equipment had circuitry to calculate the average peel strength over the length of the displacement (after passing the initial peak). For each of the sample preparation conditions (e.g., control versus field seam, surface condition of the rubber, and age of the specimen), four replicate T-peel specimens were tested.

3. RESULTS AND DISCUSSION

3.1 Results for Control Specimens

Table 1 gives the T-peel test results for the cleaned and uncleaned control specimens along with the cure (chemical crosslinking) time and the failure mode observed during delamination. The T-peel data include the range, average (four replicates), and variation for each cure time and rubber surface condition. These T-peel data are also presented in Figure 1.

The results for the control specimens were generally consistent with data presented by Martin et al. [13] and Rossiter et al. [10] for EPDM rubber joint specimens prepared in the laboratory, whereby bond strengths of the cleaned joint specimens were significantly greater than those of the uncleaned specimens. In the present study, the strengths of the cleaned and uncleaned controls, for each point of cure time, were statistically compared using analysis of variance. It was only for the third point (0.33 day) that no significant difference in strength was found. For the earlier cure times (0.08 and 0.17 day), the strengths of the uncleaned specimens were significantly higher (0.001 and 0.03 significance levels, respectively, one-sided) than those of the cleaned specimens. Reasons for the observation were not investigated. No practical importance was attributed to the observed strength difference, since the bonds had not cured beyond 4 hours time.

At the early cure times, the seam failure during peel testing for both the cleaned and uncleaned controls was primarily cohesive. This was attributed to the fact that the cure of the adhesive had proceeded only to a limited extent, and thus, surface effects did not generally contribute to the failure during peel [10,13].

At longer cure times (1 day and beyond), the peel strengths of the cleaned control specimens were significantly greater (0.05 significance level at 1 day; 0.01 or less for longer times) than those of the uncleaned controls. The cleaned controls showed continued strength increase over the time of the experiment

(Figure 2). The data set was too limited to conclude whether a maximum strength was reached. A notable observation was that the highest average strength value, 13.2 lbf/in (2.3 kN/m), was 40 percent higher than the highest average strength of 9.4 lbf/in (1.6 kN/m) reported by Martin et al. [13] in their study on the effect of surface condition on seam strength.

At the longer cure times, failure of the cleaned controls during peel testing was generally cohesive. Some areas (estimated 10% or less) of the delaminated adhesive had a shiny appearance, indicative of voids in the adhesive layer, as if little or no contact of the adhesive had occurred at these locations during bond formation [10].

In contrast to the cleaned controls, the uncleaned specimens displayed a relatively constant strength after cure times reached 1 day (Figure 1). Failure during peel testing was generally adhesive (Table 1). As previously observed in the laboratory [10, 13], the cohesive strength of the adhesive layer exceeded the strength of the interfacial bond to the uncleaned rubber surface. For the uncleaned specimens, surface effects were important, and failure during peel testing occurred at the interface of the adhesive and the uncleaned rubber surface.

3.2 Results for Field Seam Specimens

The results of the T-peel tests of the field seam specimens are given in Table 2, and plotted in Figure 2. The field seam specimens were initially tested in the laboratory two days after sampling. Their ages were, thus, 11 and 40 days.

The results of the initial tests showed that the average peel strengths ranged from 4.4 to 5.5 lbf/in (0.77 to 0.96 kN/m), with the 11-day old field seams having slightly less strength than the 40-day old specimens (Table 2). Analysis of variance indicated no significant difference (at the 0.05 significance level) between the two ages. The peel strengths in the present study were about 60% greater than the average peel strength of some field seam specimens reported previously by Rossiter et al. [10]. In the previous study, 4-month old, butyl-based seams were found to have peel strengths of about 3.0 lbf/in (1.4 kN/m). On the other hand, the peel strength values for the field seams in the present study were about 40 to 50 percent lower than those reported in previous studies [10, 13] for specimens prepared in the laboratory using cleaned rubber surfaces.

Sections of the original field specimens were kept at ambient room temperature conditions for three months after which peel tests were again performed. The intent was to determine whether the strength of the field specimens changed over time in the laboratory. The results of these tests are given in Table 2. When tested the second time, the ages of the field specimens were 99 and 128 days.

It was found that the peel strengths of the field seams underwent little change during the three month period, although one specimen attained an average strength of 6.6 lbf/in (1.2 kN/m). No statistical differences in strength values were found between the initial and second sets of data.

An important observation concerning the field seams was the mode of failure during testing. In general, the failure was cohesive, with a few small areas failing adhesively. However, about one third of the delaminated adhesive area was seen to contain shiny spots, indicative of voids in the adhesive layer. These void sections may be areas of little or no bond. In general, the areas having the shiny adhesive surface showed a cross-hatched pattern which corresponded to the slight depressions in the rubber surface created by the reinforcement in the sheet, as noted in Section 2.1.

3.3 <u>Comparison of the Results for the Field and Control Specimens</u>. The control specimens were fabricated to provide a relative indicator of the strength values that might be attainable from the adhesive-membrane system in question. The results of the peel tests for the controls and field seam specimens can be compared from Tables 1 and 2. It is evident that, in general, the field specimens had strengths much less than the cleaned controls and comparable to the uncleaned controls. However, failure of the field seams during peel testing was primarily cohesive, whereas that for the uncleaned controls was primarily adhesive. This finding suggested that surface effects were not playing a role in the relatively low peel strength of the field seams versus that of the uncleaned controls, and that other factors were having an effect. Such factors might include the mating of the two rubber surfaces during seam fabrication, or the cure of the adhesive in the field.

If the two rubber surfaces had not been totally brought and kept in contact during seam formation, as suggested by the observed areas of shiny adhesive in the delaminated specimens (Table 2), the resulting voids may contribute to reduced peel strengths of the seams.

The effect of adhesive cure on the observed strength differences between the field and cleaned controls was not examined in this limited study. Nevertheless, the observations that the field specimens had less than expected peel strengths (as compared to cleaned controls) but yet failed cohesively during testing raises a question whether cure of the adhesive in the field was, for unknown reasons, different than that of the cleaned controls in the laboratory. A similar observation regarding relatively low strength and cohesive failure was also found in a previous study [10].

The question concerning adhesive cure is important with regard to the development of a quality assurance test procedure whereby peel tests would be made in the field on newly prepared seams. In particular, the influence of the field environment, particularly moisture, on cure rate would have to be understood. Moreover, if cure rates in the field were significantly different than those in the laboratory, then the benchmark peel strength values used to indicate acceptable seam quality would need to be based on tests of field prepared and cured specimens. Data from laboratory prepared and cured specimens would only be applicable for developing benchmark strengths, if relationships between field and laboratory rates of cure were known.

3.4 SEM Analysis of Selected Control and Field Seam Specimens

Scanning electron microscopy (SEM) analysis was conducted on a limited number of specimens used in the study (Table 3) to investigate the effects of surface contaminants. The selected specimens represented a cross section of those included in the study.

The SEM analysis of the cleaned and uncleaned (as-received) rubber specimens (not fabricated into seams) provided results that were comparable to those previously obtained [10]. The uncleaned showed platelet particles of release agent covering the rubber surface. The cleaned rubber showed a rough surface, marked with crater-like depressions which are irregularities in the rubber sheet. Few platelet particles were observed on the cleaned rubber, indicating that the laboratory cleaning process removed almost all of the release agent.

It was not possible to examine the surfaces of the rubber in the case of the delaminated cleaned control specimen because the specimen peeled cohesively. SEM examination of a delaminated adhesive surface showed it to be relatively smooth, with some round unidentified particles embedded in it.

In the case of the uncleaned control, the surfaces of the two strips produced by delamination of the seam specimen were examined: one strip was the exposed rubber, essentially free of adhesive (the interface where failure in peeling was adhesive); whereas the other strip had the adhesive on it. The SEM analysis of the surface of the rubber strip showed the presence of talc-like platelet particles. This observation was, of course, not unexpected because the seam specimen was prepared without cleaning the release agent or other contaminants from the rubber surface. Similarly, SEM analysis of the surface of the adhesive from the delaminated seam specimen also showed the presence of platelet particles. The finding that platelet particles were present on the surfaces of both the rubber and adhesive suggested that failure of the seam specimen during peeling occurred to some degree through the layer of release agent present on the rubber surface.

Three field specimens were included in the SEM analysis. As previously mentioned (Section 3.2), these specimens essentially failed cohesively during peeling testing, with some small areas of apparent adhesion failure. In examining the surfaces of the adhesive created by cohesive failure, the main feature observed was the smoothness of the surfaces and some round particles embedded in them. This was comparable to the observations made on the cleaned control specimen, as just described.

In addition to examining the surface of the adhesive layer where cohesive failure of the field specimens occurred, some areas of adhesive failure were also inspected. In these cases, the corresponding surfaces of the rubber and of the adhesive were subjected to the SEM analysis. Platelet particles indicative of release agent were observed on the surfaces of both the rubber and the adhesive. For example, Figure 3 shows a small section of a field seam where the bond failed adhesively, as indicated by the raised rough area of adhesive in the center of the micrograph. Platelet particles are present of the surface of the adhesive. Similarly, Figure 4 is a photomicrograph of a small section of another field seam where adhesive failure occurred during peel testing, revealing platelet particles apparently on the surface of the rubber. The finding of the platelet particles implied that at least some of the release agent, originally present on the rubber sheet at the time of seam fabrication, was not removed during the cleaning process. Nevertheless, sufficient cleaning apparently occurred so that, in general, the strength of the interfacial bond was greater than the cohesive strength of the adhesive layer. The finding of some release agent on the surface of the rubber was consistent with results from Westley [4], who reported that cleaning did not always remove all the release agent. A previous NIST study [10] also found that some release agent may be left on the rubber sheet during cleaning.

4. SUMMARY AND CONCLUSIONS

This investigation was a limited study of EPDM rubber seams of the roof of the new "Wheeled Vehicle Facility" Building at Aberdeen Proving Ground, Maryland. The study was conducted to provide baseline data that could contribute to a data base on the characterization of newly-prepared field seams. The data may be used to support the development of a field methodology for assessing the quality of newly-prepared seams. Based on the results of the study, the following summary of key observations is made:

- At the time of the inspection, the construction of the roof was proceeding normally without concern to the COE staff monitoring the progress. In addition, the application of the EPDM rubber membrane was considered by COE staff to be satisfactory.

- Specimens of field seams removed from the membrane had low T-peel strengths in comparison to the strengths achieved by cleaned control specimens prepared on the roof using the same procedure and adhesive/rubber system. The field specimens and cleaned controls, for the most part, failed cohesively during peel testing. The adhesive layers of the delaminated controls were found to contain numerous void areas. These voids may contribute to low strength of the adhesive layer, because they represent areas of little or no bond. In addition, because the control seams cured primarily under laboratory conditions, a question was raised whether the cure of the adhesive was different in the field than in the laboratory.

- SEM analysis of uncleaned control specimens and also small areas of the field specimens that failed adhesively during peel testing showed platelet particles, typical of release agent, present on the surfaces of both the rubber strip and the adhesive layer. This finding indicated that, in these cases, some failure of the seam specimen during peeling occurred through the layer of release agent on the rubber surface.

- The SEM observation that platelet particles were present on areas of the field specimens that failed adhesively during peel testing indicated that the field cleaning procedure did not remove all the release agent on the surface of the rubber. Nevertheless, cleaning was sufficient to the extent that the interfacial bond of the seam specimens was generally greater than the strength of the adhesive layer.

5. ACKNOWLEDGMENTS

This study was supported by the U.S. Army Corps of Engineers and the National Institute of Standards and Technology. The authors extend their thanks to Mr. Cyril Miller, Corps of Engineers, Baltimore District, for his assistance in conducting the field inspections and for obtaining the field specimens. The authors also appreciate the assistance of their NIST colleagues: Geoffrey Frohnsdorff, Larry Masters and Robert Mathey, Building Materials Division, and Gregory McKenna, Polymers Division, for their review of this report, and James Lechner, Center for Computing and Applied Mathematics, for his assistance with data reduction and analysis, as well as reviewing this report.

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Table 1. Results of the T-Peel Tests for the Control Specimens

Surface Condition	Cure Time days	Peel Strength Range lbf/in (kN/m)		Av[a]	σ[b]	COV[c] %	Failure Mode
cleaned	0.08	1.0 -	1.1	1.0	0.04	4	Generally cohesive for all cleaned specimens; a few shiny spots suggestive of some poor contact of the mating surfaces.
		(0.18 -	0.19	0.18	0.01)		
	0.17	1.2 -	1.6	1.3	0.2	15	
		(2.1 -	0.28	0.23	0.04)		
	0.33	4.3 -	4.9	4.5	0.3	7	
		(0.75 -	0.86	0.79	0.05		
	1	5.4 -	5.8	5.6	0.2	4	
		(0.95 -	1.0	0.98	0.04)		
	6	7.2 -	9.9	8.8	1.2	14	
		(1.3 -	1.7	1.5	0.21)		
	9	10.5 -	12.5	11.1	0.9	8	
		(1.8 -	2.2	1.9	0.2)		
	34	12.4 -	13.9	13.2	0.6	5	
		(2.2 -	2.4	2.3	0.1)		
uncleaned	0.08	1.6 -	2.3	2.0	0.3	15	4:1 cohesive to adhesive
		(0.28 -	0.40	0.35	0.05)		
	0.17	1.5 -	2.8	2.1	0.5	24	4:1 cohesive to adhesive
		(0.26 -	0.49	0.37	0.09)		
	0.33	2.8 -	4.6	3.9	0.9	23	4:1 cohesive to adhesive
		(0.49 -	0.81	0.68	0.2		
	1	3.9 -	5.6	4.6	0.8	17	1:4 cohesive to adhesive
		(0.68 -	0.98	0.81	0.14)		
	6	3.6 -	5.7	4.4	0.9	21	primarily adhesive
		(0.63 -	1.0	0.77	0.16)		
	9	4.3 -	5.4	4.8	0.5	10	primarily adhesive
		(0.75 -	0.95	0.84	0.09)		
	34	3.5 -	6.2	5.0	1.1	22	primarily adhesive
		(0.61 -	1.1	0.88	0.19)		

[a]Average of four measurements.
[b]Standard deviation.
[c]Coefficient of variation.

Table 2. Results of the T-Peel Tests for the Field Seam Specimens

Spec. No.	Spec. Age days	Peel Strength lbf/in (kN/m) Range	Av[a]	σ[b]	COV[c] %	Failure Mode
1-1	11	3.9 - 5.5	5.0	0.7	14	All specimens appeared about the same after peeling. About 1/3 of the exposed area had areas of adhesive with a shiny surfaces indicative of poor contact with its mating surface; these areas corresponded to depressions in the rubber surface due to reinforcement in the sheet. Most of the remainder of the surface appeared to fail cohesively.
		(0.68 - 0.96	0.88	0.12)		
1-2	11	3.7 - 5.0	4.4	0.4	14	
		(0.65 - 0.96	0.77	0.07)		
1-1	99	2.0 - 8.1	4.6	2.6	32	
		(0.35 - 1.4	0.81	0.46)		
1-2	99	2.6 - 5.0	3.5	1.0	30	
		(0.46 - 0.88	0.61	0.18)		
2-1	40	4.6 - 6.3	5.2	0.8	15	
		(0.81 - 1.1	0.91	0.14)		
2-2	40	3.4 - 8.4	5.5	2.1	38	
		(0.60 - 1.5	0.96	0.37)		
2-1	128	4.6 - 7.8	6.6	1.6	24	
		(0.81 - 1.4	1.2	0.28)		
2-2	128	3.8 - 6.8	5.0	1.3	27	
		(0.67 - 1.2	0.88	0.23)		

[a]Average of four measurements.
[b]Standard deviation.
[c]Coefficient of variation.

Table 3. Seam Specimens Subjected to SEM Analysis

SEM Specimen	Description
1	Rubber specimen in its as-received condition.
2	Rubber specimen cleaned in the laboratory by scrubbing with water and detergent and then wiping with hexane.
3	A delaminated cleaned control specimen; the seam specimen was fabricated in the field using rubber that was cleaned with a proprietary wash solution.
4	A delaminated uncleaned control specimen; the seam specimen was fabricated in the field using uncleaned rubber.
5	A delaminated field specimen cut from the membrane.
6	A second delaminated field specimen cut from the membrane.
7	A third delaminated field specimen cut from the membrane.

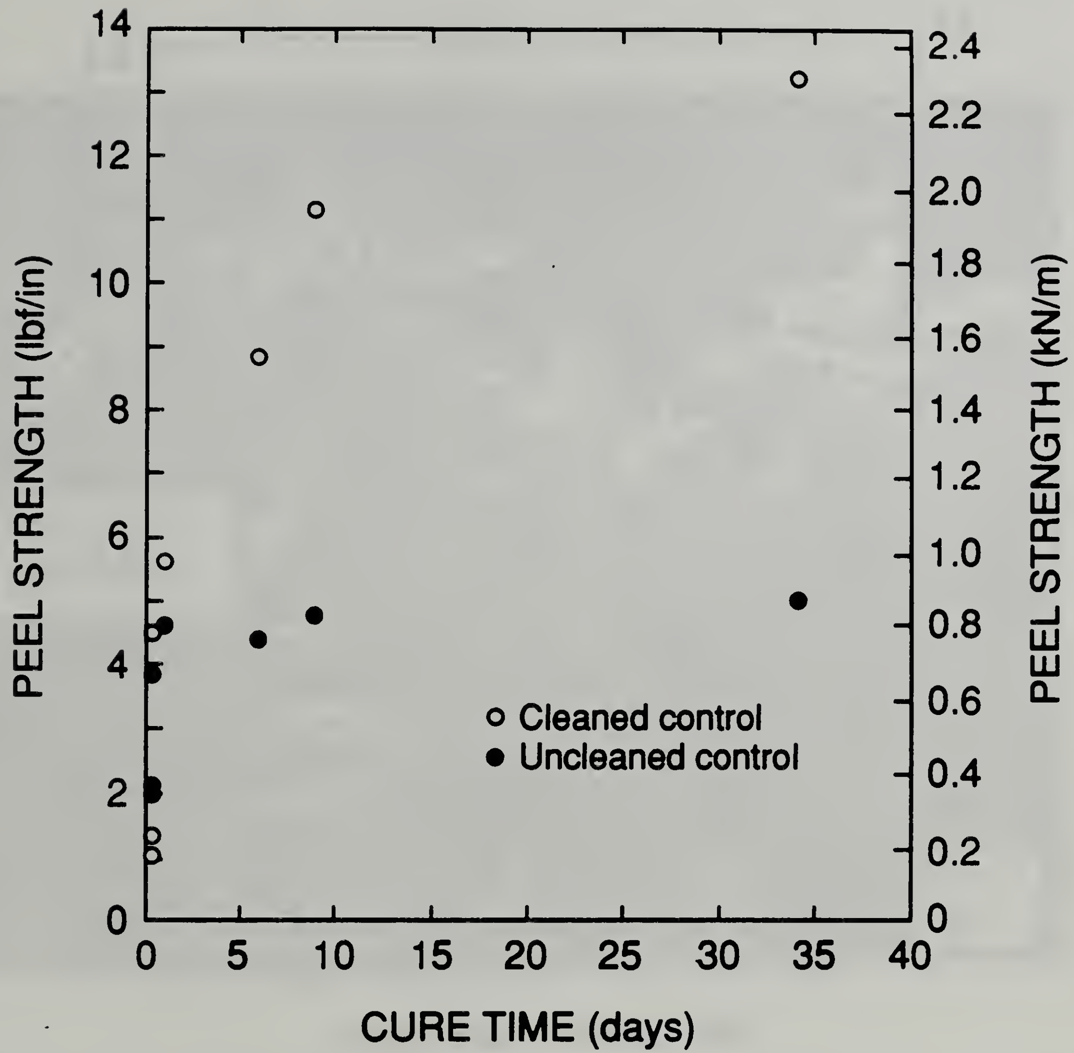

Figure 1. T-peel strength of the control specimens over time.

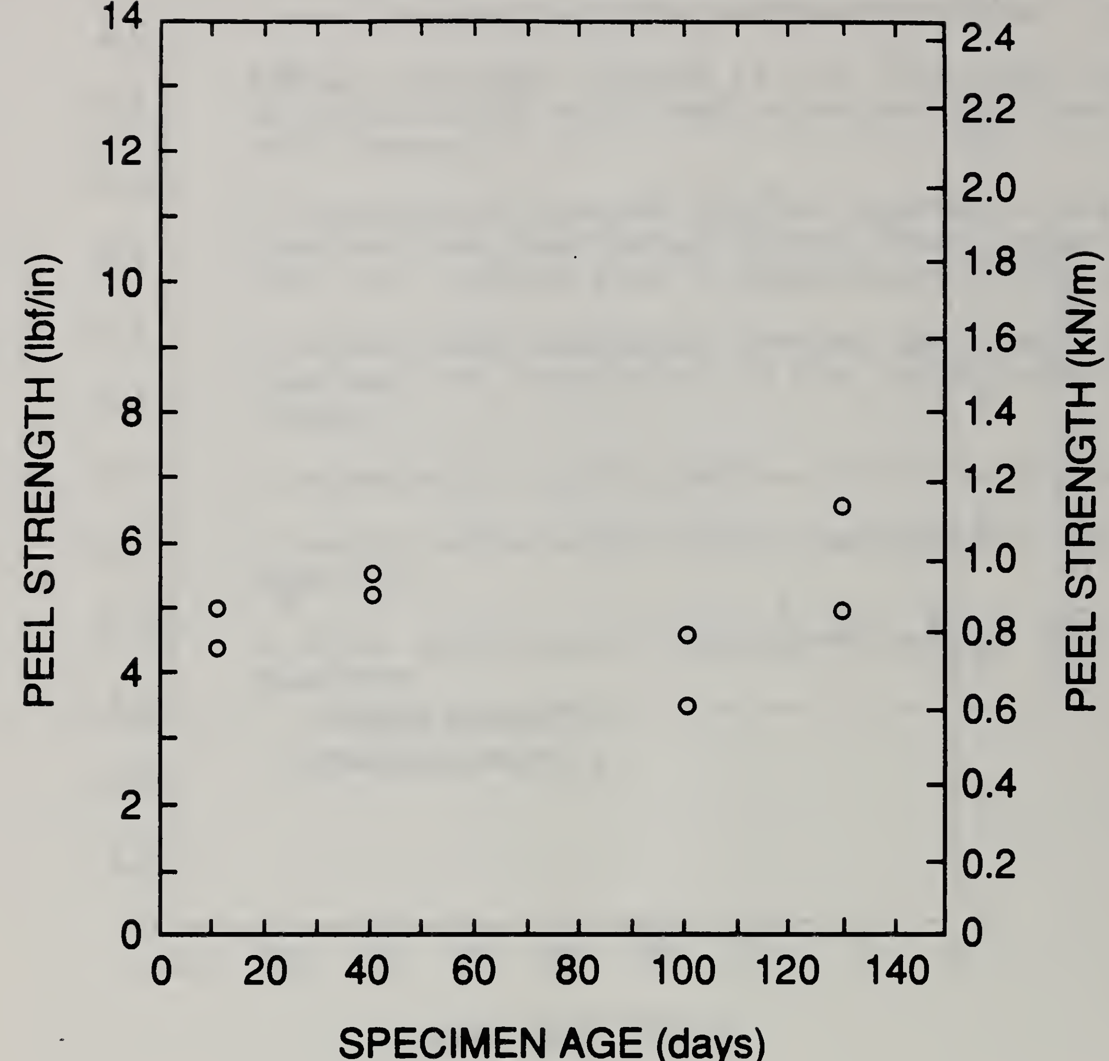

Figure 2. T-peel strength of the field specimens.

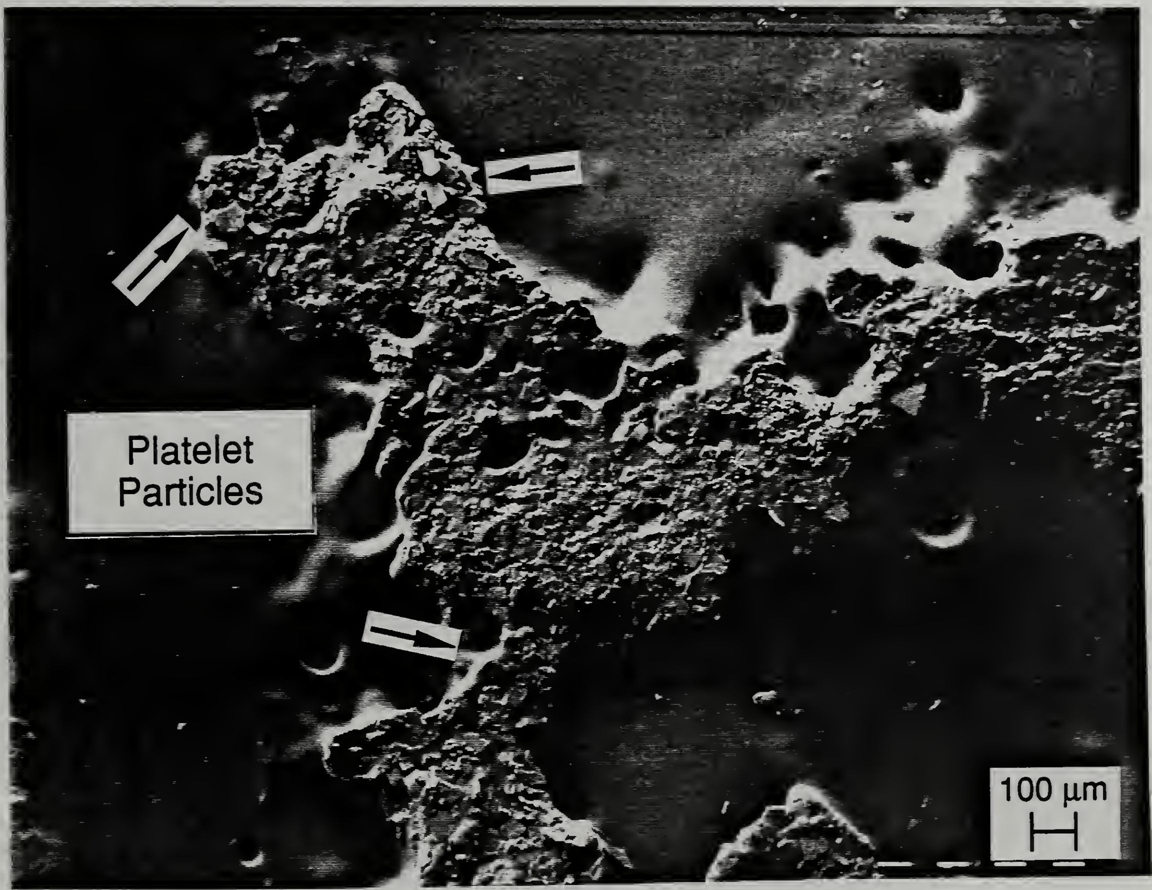

Figure 3. Photomicrograph (x100 magnification) of a small section of a field seam where adhesive failure showed the presence of platelet particles on the adhesive surface. The arrows indicate examples of areas having particles.

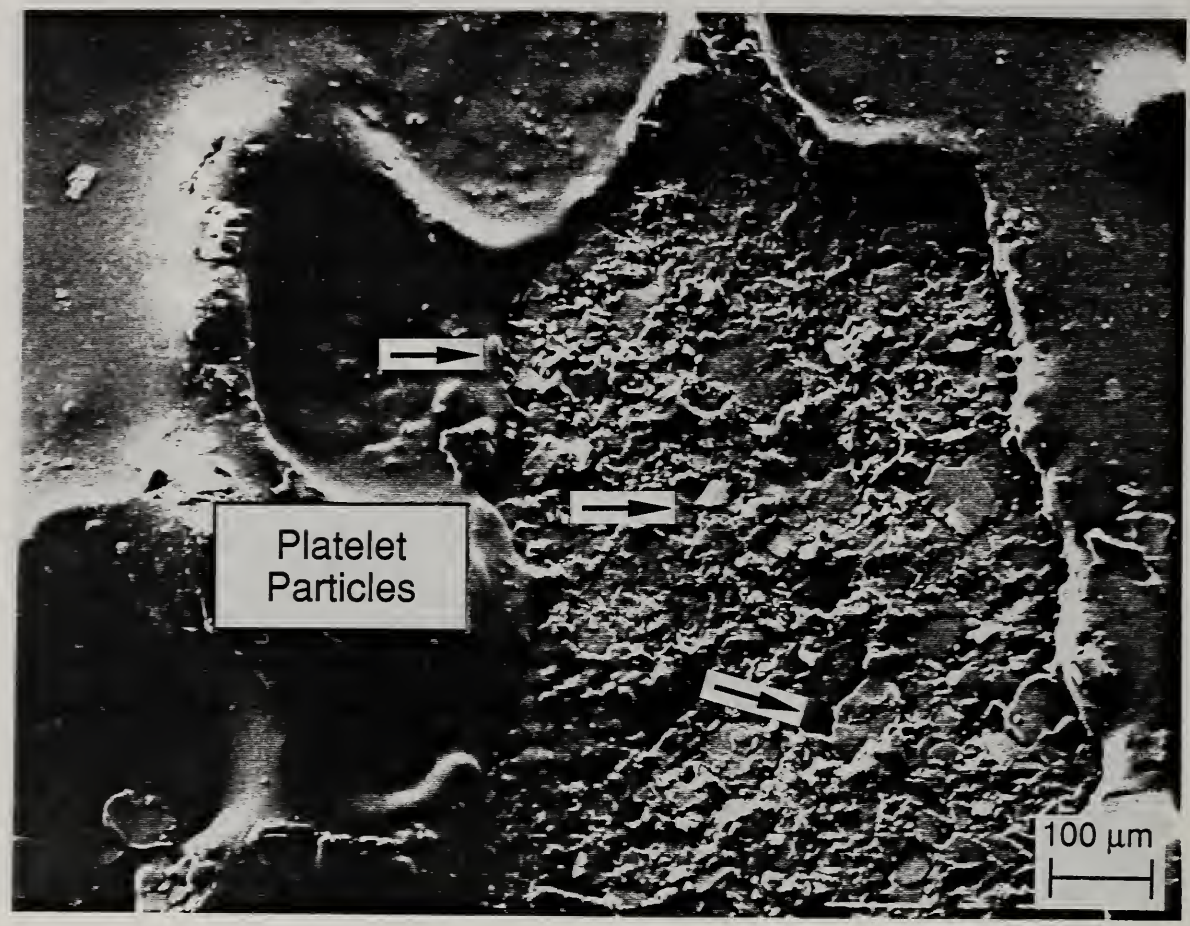

Figure 4. Photomicrograph (x30 magnification) of a small section of a field seam where adhesive failure revealed the presence of platelet particles on the rubber surface. The arrows indicate examples of areas having particles.

NIST-114A (REV. 3-89)

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION OR REPORT NUMBER
NISTIR 89-4155

2. PERFORMING ORGANIZATION REPORT NUMBER

3. PUBLICATION DATE
OCTOBER 1989

4. TITLE AND SUBTITLE

Report of Roof Inspections: Characterization of Newly-Fabricated Adhesive-Bonded Seams at an Army Facility

5. AUTHOR(S)

Walter J. Rossiter, James F. Seiler, and Paul E. Stutzman

6. PERFORMING ORGANIZATION (IF JOINT OR OTHER THAN NIST, SEE INSTRUCTIONS)

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
GAITHERSBURG, MD 20899

7. CONTRACT/GRANT NUMBER

8. TYPE OF REPORT AND PERIOD COVERED

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (STREET, CITY, STATE, ZIP)

US Army Engineer District, Baltimore
PO Box 1715
Baltimore, MD 21203-1715

10. SUPPLEMENTARY NOTES

☐ DOCUMENT DESCRIBES A COMPUTER PROGRAM; SF-185, FIPS SOFTWARE SUMMARY, IS ATTACHED.

11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

This investigation was a limited study of seams in EPDM rubber membranes of the roof of the new "Wheeled Vehicle Facility" Building at Aberdeen Proving Ground, Maryland. The study was initiated at the request of the Corps of Engineers (CoE) to provide data that could contribute to a data base on the characterization of newly-prepared field seams. The investigation was beneficial to the National Institute of Standards and Technology (NIST) because it complemented laboratory research on test methods for evaluating seams of vulcanized rubber roof membranes.

Field seam specimens were taken from the roof and analyzed for peel strength and surface condition of the rubber. At the time of the inspection, the application of the EPDM rubber membrane was considered by CoE personnel to be proceeding satisfactorily. Peel tests indicated that the field seams had low bond strengths in comparison to the strengths achieved by cleaned control specimens prepared on the roof using the same procedure and the same adhesive/rubber system. Both the field specimens and cleaned controls, for the most part, failed cohesively during peel testing. Unlike the cleaned controls, the adhesive layers of the delaminated field seams were found to contain numerous void areas. These voids may contribute to low strength of the adhesive layer, because they represent areas of little or no bond. In addition, because the control seams were cured primarily under laboratory conditions, a question was raised whether the rates of adhesive cure in the field and laboratory were different. Scanning electron microscopy (SEM) analysis of uncleaned control specimens and also small areas of the field specimens that failed adhesively during peel testing showed platelet particles, typical of the release agent, present on the surfaces of both the rubber strip and the corresponding adhesive layer. This finding indicated that, in these cases, some peeling during testing occurred through the layer of release agent on the rubber surface.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

adhesive-bonding; bond strength; EPDM rubber; field inspection; low-sloped roofing; membranes; roofs; seams; scanning electron microscopy (SEM) analysis; surface condition.

13. AVAILABILITY

- X UNLIMITED
- ☐ FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NATIONAL TECHNICAL INFORMATION SERVICE (NTIS).
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- X ORDER FROM NATIONAL TECHNICAL INFORMATION SERVICE (NTIS), SPRINGFIELD, VA 22161.

14. NUMBER OF PRINTED PAGES
30

15. PRICE
A03

ELECTRONIC FORM