EPDM AND PUF ROOFING LONG-TERM FIELD TEST RESULTS

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Ethylene-propylene-diene terpolymer (EPDM) and spray-applied polyurethane foam (PUF) roofing systems were installed at Fort Lewis, Wash. and Fort Benning, Ga. for a long term evaluation. This work was part of the research performed by the U.S. Army Construction Engineering Research Laboratory (USACERL) to identify alternatives to conventional built-up roofing (BUR) for military construction and reroofing. This paper reports the test results which document the property changes of EPDM and PUF roofing systems for different applications and climates.

Membrane samples were taken periodically based on a schedule of every six months for the first two years and annually for the next five years. Laboratory testing of properties deemed essential to successful performance was completed by an independent testing laboratory using American Society of Testing and Materials (ASTM) methods when possible. Where no ASTM test method existed, tests developed by U.S. Bureau of Reclamation (USBR) and the U.S. Naval Civil Engineering Laboratory (NCEL) were used. The cutting of samples necessitated repairs and the success of patching the weathered membranes could therefore be evaluated. Repairability is an important factor in obtaining the full service life expected of the system.

Laboratory testing indicates that discernible changes have occurred in the physical and mechanical properties of the EPDM membranes at the two test sites. The EPDM has become harder, weaker and less elastic. Although testing of the seams shows strengths are minimal, field performance of the original seams appears adequate. The PUF membranes performed well in undisturbed areas but patches where samples were taken failed to permanently bond to the existing PUF. Substantial reduction in interlaminar tensile strength and coating adhesion does not appear to have had an impact on the successful performance of the PUF test roofs.

KEYWORDS

EPDM, field tests, low-slope roofing, PUF, roofs, single-ply roofing.

INTRODUCTION

The U.S. Army Construction Engineering Research Laboratory (USACERL) has been investigating alternatives to BUR since the late 1970s. As part of this effort, experimental roofs of single-ply, ethylene-propylene-diene terpolymer (EPDM, a synthetic rubber) sheet and spray-applied polyurethane foam (PUF) with elastomeric coatings were installed at Fort Benning, Ga. and Fort Lewis, Wash. Construction of these systems was described in USACERL Technical Report M-298, "Construction of Experimental Roofing."[1] Laboratory testing was performed on membrane samples taken periodically from each test roof for seven years, measuring mechanical and physical properties and their changes over time. The results of these tests for the first two years of service life were described in USACERL Technical Report M-357, "Field Test Results of Experimental EPDM and PUF Roofing."[2] The intent of this paper is to document results of the field test program for the remaining five years to evaluate the EPDM and PUF systems, and the effect of the climate on the aging and weathering of the materials.

DESCRIPTION OF TEST ROOFS

Two EPDM roofs, which used membrane products from the same manufacturer, were constructed; one at Fort Benning, Ga., and one at Fort Lewis, Wash. Both are fully adhered, with the membrane bonded to the insulation surface. The insulation is sufficient to give the roofing system an overall R-value of 20. The system at Fort Benning consists of a steel deck, 7.6cm (3 in.) of composite board insulation mechanically fastened to the deck, and 1.5mm (60-mil) thick single-ply EPDM membrane. The system at Fort Lewis consists of a poured-in-place concrete roof deck, a one-ply vapor retarder of No. 43 asphalt-saturated and coated glass fiber base sheet installed in hot asphalt, 6.4cm (2-1/2 in.) of rigid polyurethane board stock with asphalt-saturated organic felt facer sheets installed in hot asphalt, and a 60-mil thick single-ply EPDM membrane. Figure 1 shows cross sections of the EPDM roofs.

A PUF roof was also constructed at each of the two sites. The system at Fort Benning consists of a poured-in-place concrete roof deck, a two-ply vapor retarder of No. 15 asphalt-saturated organic felt, a minimum of 8.9cm (3-1/2 in.) of sprayed PUF, and a minimum of 0.5mm (20 mils) of a single-component, moisture-cured silicone coating, applied in two coats with granules in the second coat. The system at Fort Lewis consists of a poured-in-place concrete roof deck, one ply of No. 43 asphalt-saturated and coated glass fiber base sheet in hot asphalt, a minimum 7.6cm (3 in.) of sprayed PUF, and a coating consisting of a base coat of a two-component polyurethane elastomer having a minimum thickness of 0.4mm (16 mils) and a top coat of chlorosulfonated polyethylene (CSPE) having a minimum thickness of 0.1mm (4 mils) with granules. The total minimum dry film thickness was specified as 0.5mm (20 mils), but was actually determined to be 0.25mm (10 mils). These specified total thicknesses of 20 mils are less than the minimum total thicknesses of 30 mils allowed by the Corps of Engineers Guide Specifications (CEGS) for elastomeric protective coatings. Figure 2 shows the cross sections of the PUF test roofs.

DESCRIPTION OF TEST PROGRAM

The test program was designed to determine how weathering would change the mechanical and physical characteristics of the roofing membranes as well as their repairability. Properties selected for study were those deemed essential to successful performance of the materials in a roof assembly. ASTM Standard Test Methods were used when possible to determine these properties. Where none existed, tests developed by the U.S. Bureau of Reclamation (USBR) or the U.S. Naval Civil Engineering Laboratory (NCEL) were used. The test methods used for the EPDM and PUF test roofs are listed in Tables 1 and 2, respectively.

An initial set of tests was designed to establish the mechanical and physical characteristics of the materials at the time of application. Subsequent tests were scheduled every six months for two years, and once a year thereafter to establish a pattern of performance or to note changes in properties.

Each test consisted of analyzing five samples and averaging the results. One sample was cut near each corner of the roof and one near the center so that the results would have minimal dependence on the location. Data resulting from the testing are presented on graphs which show the linear or quadratic best fit curves. In addition to the laboratory tests, visual inspections were made annually to check for changes in appearance, blistering, cracking, pinholing, loss of granules, mechanical damage from foot or equipment traffic, or loss of adhesion of EPDM membrane or PUF coating.

CLIMATE COMPARISONS BETWEEN FORT LEWIS AND FORT BENNING

The Fort Lewis area is characterized by equable temperatures, a pronounced rainy season and considerable cloudiness, particularly during the winter months. The prevailing southwesterly circulation keeps average winter daytime temperatures between 4 and 10°C (40 and 50°F). The agreeable temperatures in the summer months (normal daytime highs between 21 and 29°C (70 and 85°F) and the light precipitation characteristic of the warm season give Fort Lewis a very pleasant summer climate. Fort Benning has warm, humid summers (average 74 days with temperatures above 32°C (90°F) and short mild winters. Relative humidity averages are moderately high, as would be expected from its location in relation to the Gulf of Mexico and Atlantic Ocean.

Comparing the two locations, Fort Lewis has a relatively stable temperature range throughout the year, while Fort Benning has warmer temperatures in the summer and about the same temperatures as Fort Lewis in the winter. Fort Benning also averages more than twice the number of clear sunny days than does Fort Lewis (113 to 54). This results in a higher heat load and ultraviolet radiation on the roofs at Fort Benning.

INITIAL EPDM PROPERTIES

All EPDM membranes should meet ASTM D 4637-87.[3] The EPDM materials delivered to the two sites were the products of the same manufacturer. The mechanical properties of the delivered materials (tensile strength, elongation and hardness) all exceeded the values that were specified, which were the minimums stated in the manufacturer's literature. These initial values indicate good-quality rubber sheet. The field seams, which were made using a neoprene adhesive, had seam strengths which did not exceed the specified values in all cases. The field seam "T" peel strength at Fort Benning was very low, with an average of 0.14 N/mm (0.8 lb./in.). The peel strength at Fort Lewis is 0.44 N/mm (2.5 lb./in.), which is considered more typical of expected values. The seam shear strength at Fort Benning is 3.2 N/mm (18 lb./in.), or only 20 percent of the sheet tensile strength. The seam shear strength at Fort Lewis is 5.1 N/mm (29 lb./in.) or 29 percent of the sheet strength. According to the manufacturer, the shear strength of the seam should be at least 30 percent of the sheet strength.

Of the physical properties, only the brittleness, ozone resistance and water vapor permeability were published by the manufacturer. Water absorption and abrasion loss were determined so that the effect of aging in these properties could also be measured. The brittleness value was exceeded and the ozone resistance was met, but a difference was noted for the water vapor permeability, which was specified as 2.0 perm-mils. According to the manufacturer, this is neither a maximum nor minimum, but is the actual value as determined in the laboratory. The measured value at Fort Benning of 0.06 perm calculates to 3.6 perm-mils while the Fort Lewis value of 0.03 perm calculates to 1.98 perm-mils. Any value less than one perm is considered to be a vapor retarder, and the manufacturer describes this product as impermeable. The manufacturer's determination was conducted by Procedure BW of ASTM E 96-80;[4] the results of the USACERL test were obtained from Procedure B of the same test method. Test method E 96 states that "agreement should not be expected between results obtained by different methods," so even though the measured values are not the same, they are of the same order of magnitude and are close. What is significant is the change that occurs in the value over time.

EPDM PROPERTY CHANGES OVER TIME

Figures 3 through 9 depict the changes in physical and mechanical properties of the EPDM membrane at Forts Benning and Lewis. Three points are worth noting. First, tests indicate the material has the normal tendency of rubber products to show slight increases/decreases in mechanical properties during exposure to heat. For these roofs, tensile and abrasion values increased between one and three years after installation and then showed a gradual decrease. Second, changes in these mechanical properties are readily measured and, even after seven years at Fort Benning, the properties were no less than 90 percent of the manufacturer's published specifications. Third, the EPDM membrane at Fort Benning aged more rapidly than the membrane at Fort Lewis. This difference is most evident in the changes in elongation and hardness. The major reason for this difference is most likely the level of solar radiation (UV degradation). Other factors may include material formulation and contaminants.

Tests by others[5] indicate that the EPDM roof materials display increased tensile strength, reduced elongation properties and increased hardness after accelerated aging. Results of the field test (Figures 3, 4 and 5) indicate similar effects of natural aging. There was an initial increase in tensile properties (Figure 3) after exposure of six months at Fort Benning, but the succeeding tests indicate a gradual return to just below the original value after six years. At Fort Lewis, an increase was evident up to 18 months with a steady drop to just below the original value after five years. Decreases in elongation (Figure 4) and increases in hardness (Figure 5) inidcate long-term hardening of the EPDM at both locations. The abrasion loss (Figure 6) showed steady increases after declining during the first three years. Water absorption (Figure 7) of the membrane at Forts Benning and Lewis steadily increased over time.

Seam strength testing was performed as scheduled for the EPDM at Fort Lewis, but not at Fort Benning due to poor sample conditions. Some of the Fort Benning samples did not include seams and other samples were not large enough to cut all of the necessary test specimens. The shear strength of the seam at Fort Lewis (Figure 8) decreased to a low of 4.2 N/mm (24 lb./in.) after two years and stabilized. The T-peel strength (Figure 9) dropped from an initial value of 0.44 N/mm (2.5 lb./in) to 0.33 N/mm (1.9 lb./in.) after two years and stablized. The seams lost 16 percent of their initial strength in shear and up to 24 percent of their initial strength in peel. The drop in peel strength at Fort Lewis apparently did not affect the performance of the seams. The seams at Fort Benning were initially very weak, but show a substantial increase in both peel and shear strengths with time. At both locations, the system is fully adhered, so the strength of the seams is not as important as it would be if the membrane were either loose laid or mechanically fastened. An important finding of these field tests was that the original seams at both locations maintained their watertight integrity, despite the aging of the membrane surfaces, except for one seam at Fort Benning.

SIGNIFICANCE OF DATA—EPDM

The collection and analysis of roof temperatures and weather conditions is part of the overall study to evaluate alternative roofing systems. How these roof systems will age (i.e., what changes will occur in their physical characteristics over time) is of great concern to this program. Previous research indicates that EPDM roof materials display reduced elongation properties, increased tensile strength and increased hardness after accelerated aging. Test results of the physical characteristics of the EPDM roofs at Forts Lewis and Benning agree with the elongation and hardness changes, but disagree with tensile strength changes. There was an initial increase in tensile strength properties after a six-month exposure at Fort Benning, but the tests during the last seven years of exposure indicate a gradual return to near the original levels. At Fort Lewis, a small increase was evident after an 18-month exposure, but this was followed by a decline similar to that at Fort Benning.

Long-term exposure has induced property changes which in some cases were different from those anticipated. It is now apparent that EPDM ages more rapidly under stronger solar exposure, as is shown by the property changes at Fort Benning. Decreases in tensile strength and elongation, and increases in hardness and water absorption all point to solar-induced degradation. These data, although significant in understanding the property changes, should not necessarily affect the longevity of the membrane itself.

VISUAL INSPECTIONS—EPDM

Each roof was inspected annually as part of the evaluation process. During each inspection, the roof was carefully checked for visible signs of deterioration, giving special attention to the patches where samples for testing had been removed, as well as to flashings and indications of maintenance or repair.

Installation of EPDM fully-adhered systems at Forts Lewis and Benning afforded an excellent comparison of the effect of direct exposure on repairability when the same material was installed in two completely different climatic conditions.

Throughout this study, problems in repairing the EPDM roof at Fort Benning were evident. Virtually all the problems were caused by repair procedures that were temporary at best and were not up to the standards of a professional roofer. The worst patches were made with an unidentified grey adhesive. Other improper patches were made with a lap sealant or a bonding adhesive rather than a seaming adhesive.

Patches made with proper materials and procedures, which included preparation of the mating surfaces by cleaning with heptane or splice wash and using scouring pads or sandpaper on rough surfaces, were not without fault. The neoprene cement resulted in a low peel strength. Despite this, the patches did appear watertight. This is no longer of great importance because the neoprene has been replaced by butyl-based splicing cement. Peel strength for the butyl adhesive appears more than adequate for normal conditions. After more than eight years of weathering, the membrane at Fort Benning can still be repaired with quality patches using the butyl-based adhesive. As with any roofing system, proper application procedures, such as avoiding T-joints, improves performance.

INITIAL PUF FOAM AND COATING PROPERTIES

The initial values of the PUF properties reflect the differences between the products of two manufacturers. Densities of the foams were within the specified range. Closed-cell content exceeded the 90 percent value normally expected for sprayed PUF within the specified density range. Compressive strengths of the foam at Fort Benning exceeded the specified value of 276 KN/m^2 (40 lb./in.^{2}), but the foam at Fort Lewis, with a minimum compressive strength of 241 KN/m^2 (35 lb./in.^{2}), did not meet specifications. Neither foam met the specified tensile properties (testing was performed on blocks of foam which included all lifts, and failure always occurred at the lift line), but the higher tensile strength at Fort Benning indicates better interlayer adhesion than at Fort Lewis. In general, the polyurethane foam at Fort Lewis was found to be slightly different in cell structure and material composition from the foam at Fort Benning. This difference is indicated by lower strength, higher water vapor transmission, and greater dimensional change.

Dimensional stability values are reported by the manufacturers as the percent change in linear dimension in the direction of foam rise. The samples from the field were allowed to expand unrestrained. Linear dimensional stability values in the direction of rise were comparable to those claimed by the manufacturer of the foam used at Fort Lewis.

The urethane base coat/Hypalon top coat system was selected to obtain a basis for evaluating a different coating. Each system included applying ceramic granules to the top coat while it was still fluid. For the coatings, the only values specified were minimum thickness and maximum perm rating. The variation in thicknesses cannot be attributed only to foam surface texture, since the foam at Fort Lewis had a smoother surface than at Fort Benning, and the coating at Fort Benning met the specified minimum thickness. Application technique undoubtedly influenced the results. Both coatings met the specified water vapor transmission requirements.

Measured and advertised properties for the coatings could not be compared. Since coating thicknesses were so varied for any given sample, determination of tensile properties would be meaningless. The manufacturers do not publish the brittle temperatures of their products, so the determination of this property was for initial characterization only, as was the glass transition temperature. It should be mentioned that the glass transition temperature is not the same as the brittle temperature, but is a temperature range in which heat is absorbed as the material undergoes a phase change.

PUF FOAM AND COATING PROPERTY CHANGES OVER TIME

It must be emphasized that PUF, as used in liquid-applied roofing, is manufactured on-site, under ambient atmospheric conditions, and not within the enclosed space of a factory under controlled conditions. Trends, therefore, become more important than singularities that may result from a change in any one of many localized conditions.

The compressive strength (Figure 10) has shown a slight increase with time from the initial value at both locations, each staying near or above the required minimum of 276 KN/m^2 (40 lb./in.^{2}). Compressive strength is an important property of the foam, as it is the one property which most resists traffic on the roof. The foam should be capable of bearing all anticipated traffic loads throughout its life. Tensile interlaminar strength decreased at both sites (Figure 11). The loss of tensile strength in the foam at Fort Lewis was more rapid, indicating that the specific foam used there lost its ability to adhere to itself, leading to the possibility of future separation of the layers.

Figure 12 shows the densities of foam samples. Recommended minimum density is 40 kg/m^3 (2.5 lb./ft.^{3}). This is to ensure minimum compressive strength requirements of a properly mixed spray. The foam density at Fort Lewis has remained relatively unchanged. However, at Fort Benning, the density has shown a 28 percent increase after the initial sampling.

Water absorption of the foam at Fort Benning (Figure 13) remained steady, staying below 60 g/m^2 (0.0123 lb./ft.^{2}) through seven years. At Fort Lewis the water absorption remained at approximately its initial value for four years and then showed a significant increase during the last two years.

Figures 14 through 16 outline changes of foam and coating assembly properties. Impact and indentation properties improved over time as coating adhesion declined. Impact strength increased at about the same rate at Fort Benning and Fort Lewis. The rate of increase in indentation strength was slightly greater at Fort Lewis. At both sites, the coating adhesion has shown a large decrease. Despite this degradation, visual inspections have not shown any significant occurrences of blisters within the foam/coating interface or peeling of the coating.

SIGNIFICANCE OF DATA—PUF

Of the physical properties of PUF which were tested, density, compressive strength, interlaminar bond strength and water absorption show both negative and positive changes. The only possibly significant change appears to be at Fort Lewis, where interlaminar bond strength declined significantly after two years and water absorption increased significantly after four years. Average coating adhesion values of 110 to 120 N/cm^2 (160 to 174 lb./in.^{2}) at the two sites have declined to average values of 65 to 95 N/cm^2 (94 to 138 lb./in.^{2}) over the seven-year test period.

Degradation of the PUF roof is probably not related to temperature or exposure, but most likely is a direct result either of the application problems encountered by the contractor, the formulation of the resins by the manufacturer, the expected deterioration of the coating with time, or a combination of these.

VISUAL INSPECTIONS—PUF

PUF roofs at both Forts Benning and Lewis were repaired with varying degrees of success as the years passed. Guidelines[6] based on existing recommendations from the Naval Civil Engineering Laboratory (NCEL) utilizing two-component canned froth foam were to be used in making the repairs. The actual repairs which were performed were not well documented. In some cases, the problems could be traced to inadequate cleaning or other surface preparation. In other cases, there was no apparent reason for failure. Due to the inadequate repairs, the PUF roof at Fort Benning was so saturated with water after seven years that it was decided to remove it and apply a new membrane of a different type, which would not be disturbed. At Fort Lewis, the most serious deterioration was to the coating, which after seven years was almost worn through. However, this is not uncommon for a PUF roof coating. Wet areas and broken patches would have to be removed and refoamed before coating, but once this was accomplished the roof would remain undisturbed except for visual inspections.

Previously published maintenance and repair instructions, although complete, did not contain estimates of the expected life of a PUF roof repair. While it is not known for certain that incompatibility between the original and repair foams existed at Forts Benning and Lewis, it was observed in almost all cases that the repair foam ultimately became unbonded from the originally installed foam.

CONCLUSIONS AND RECOMMENDATIONS

From the experiences during a seven-year period of exposure, sampling and repairing, the following conclusions can be drawn about EPDM and PUF roofing materials.

- The EPDM membranes on the test roofs performed satisfactorily through the seven-year period and appear to have many years of satisfactory performance left. The membrane can be repaired, but this requires the proper materials and procedures as recommended by the membrane manufacturer. Care must be taken in preparing the seam area and applying the adhesives correctly.
- Mechanical property changes appear directly related to solar exposure. Changes at Fort Benning, Ga. were greater and occurred quicker than at Fort Lewis, Wash. which has considerably less solar radiation through the year.

- The replacement of neoprene-based splicing cement with butyl-based splicing cement has improved the performance of properly made seams (especially repair seams on aged membrane).
- The undisturbed areas of both PUF roofs remained in essentially good condition, although failure of the repairs was unexpected. This indicates that a well-applied PUF roof should give excellent service, needing only a recoating as the original coating wears away. The tests indicated that both the urethane/Hypalon coating used at Fort Lewis and the silicone coating used at Fort Benning are good, serviceable materials, and should continue to be used.
- The repair techniques which were made on the PUF test roofs were inadequate. The PUF seems to be dependent on compatibility of materials, although aging of the foam should not be discounted.

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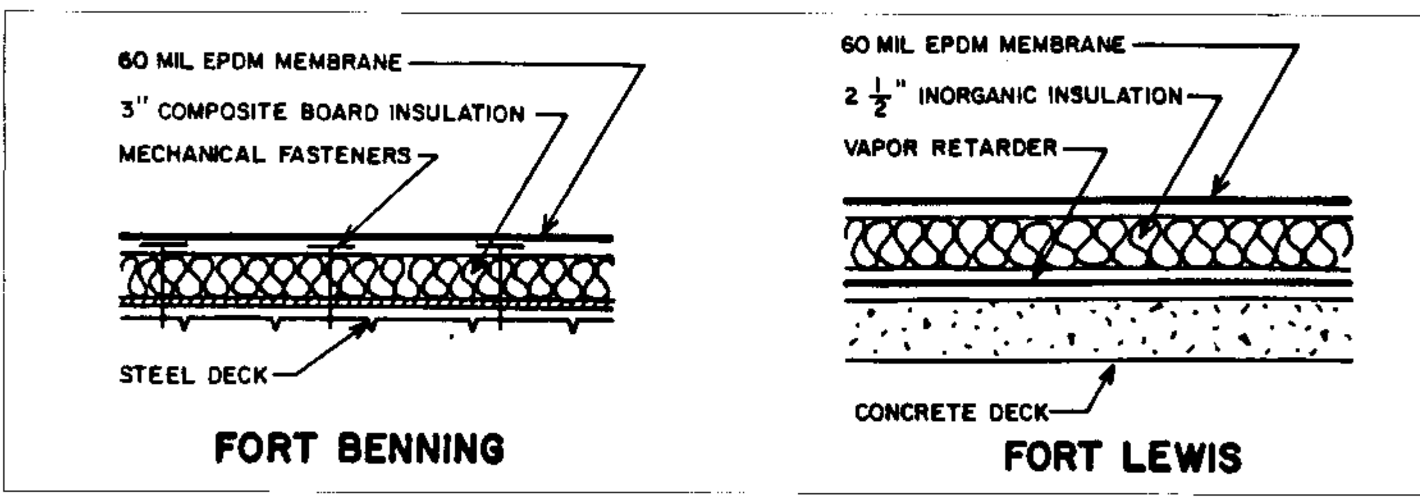

Figure 1 *EPDM roofs, cross sections.*

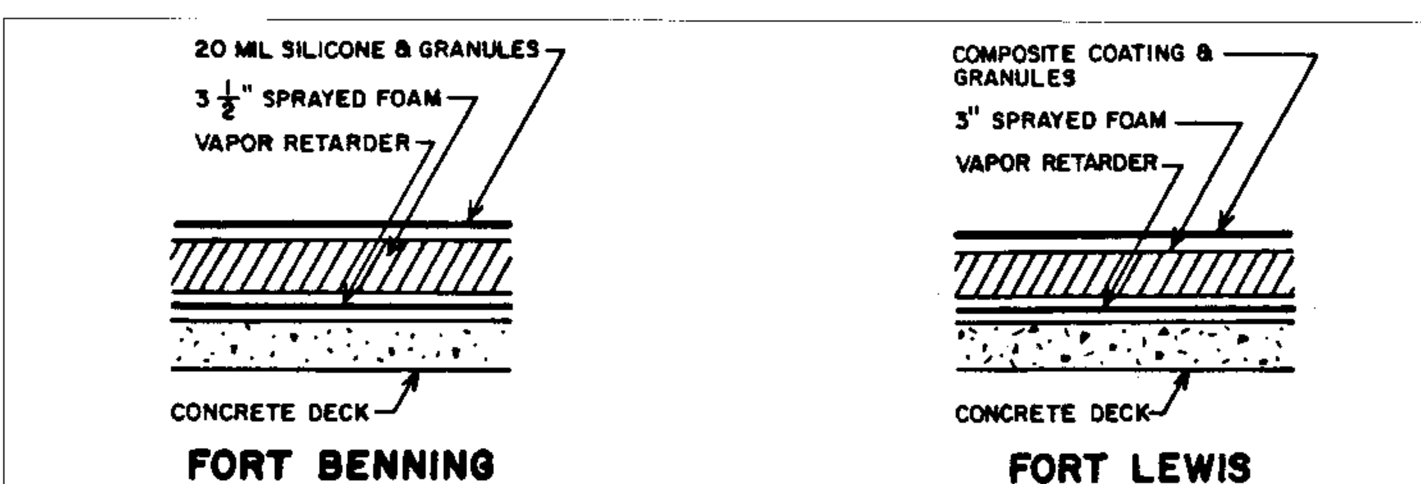

Figure 2 *PUF roofs, cross sections.*

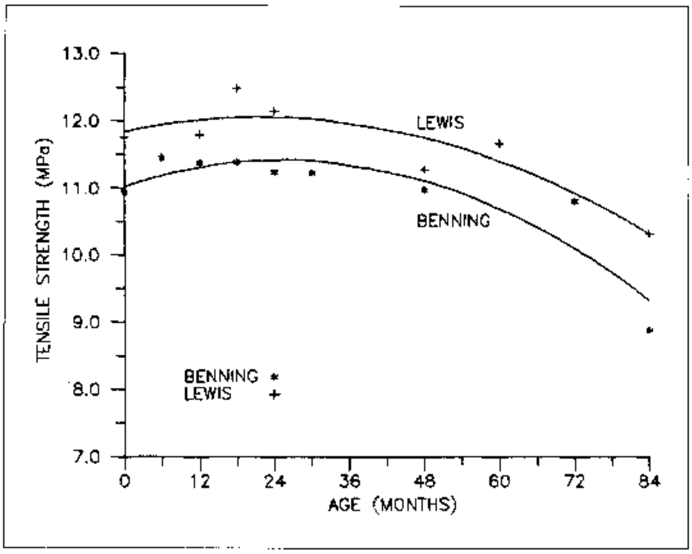

Figure 3 *EPDM tensile strength.*

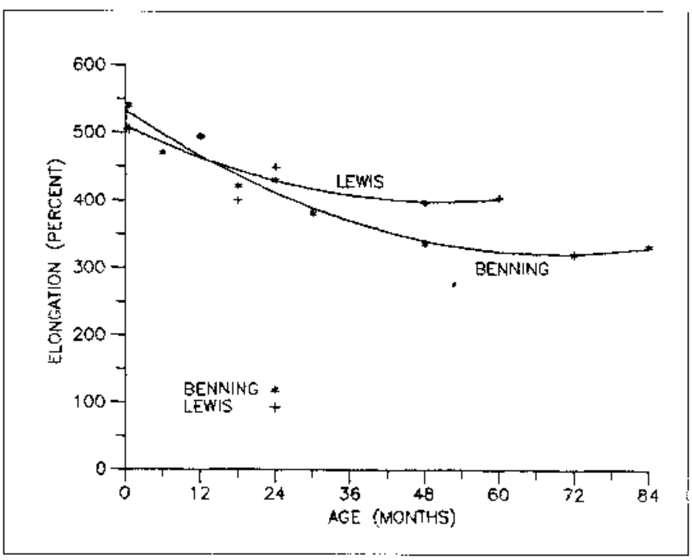

Figure 4 *EPDM elongation.*

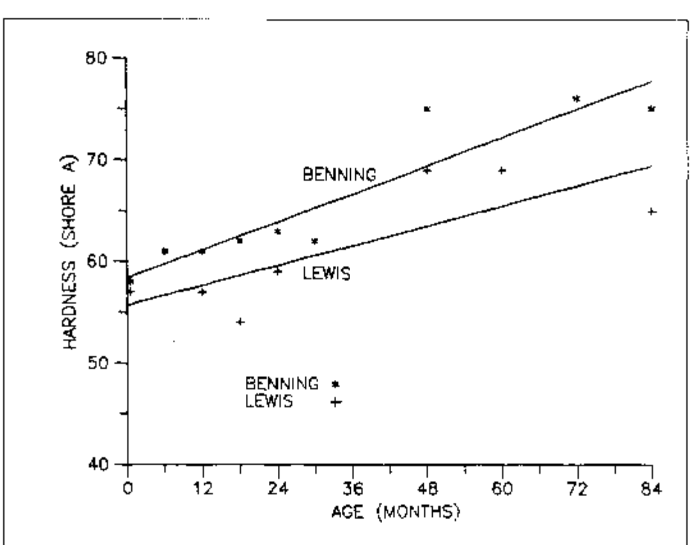

Figure 5 *EPDM hardness.*

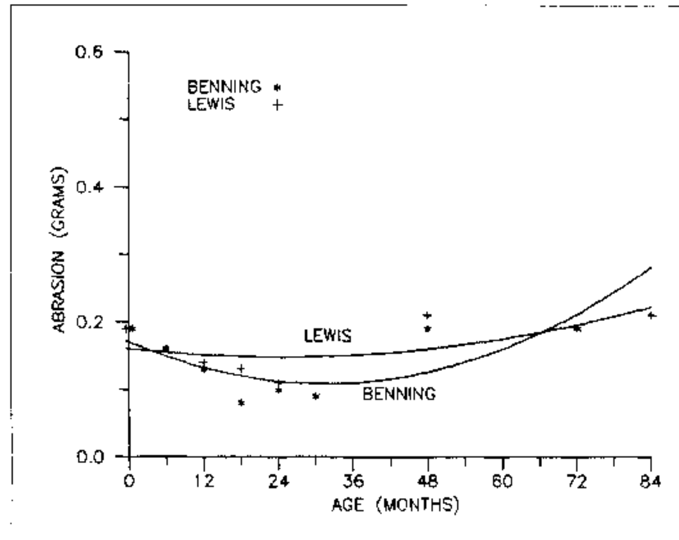

Figure 6 *EPDM abrasion loss.*

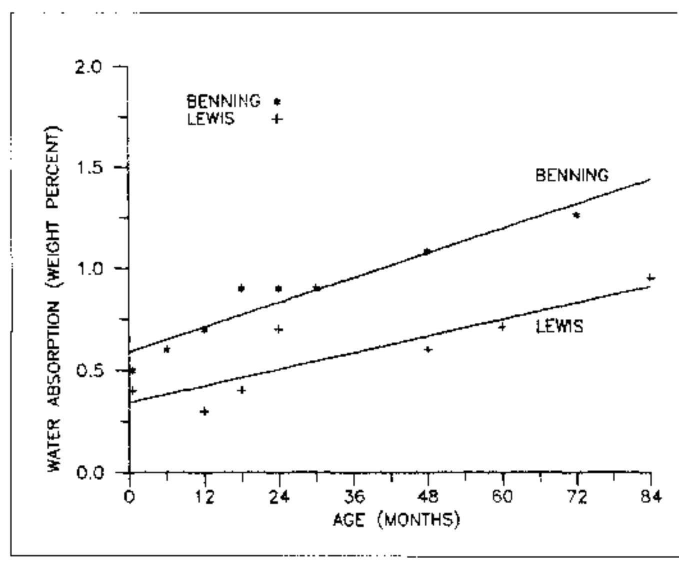

Figure 7 *EPDM water absorption.*

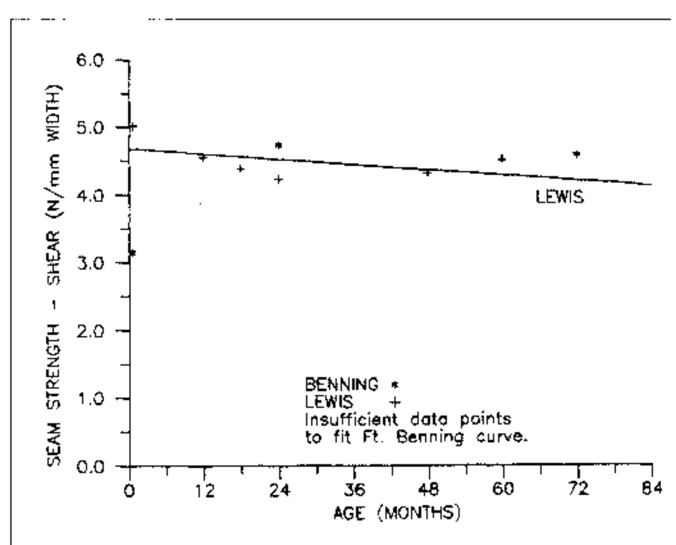

Figure 8 *EPDM seam strength—shear.*

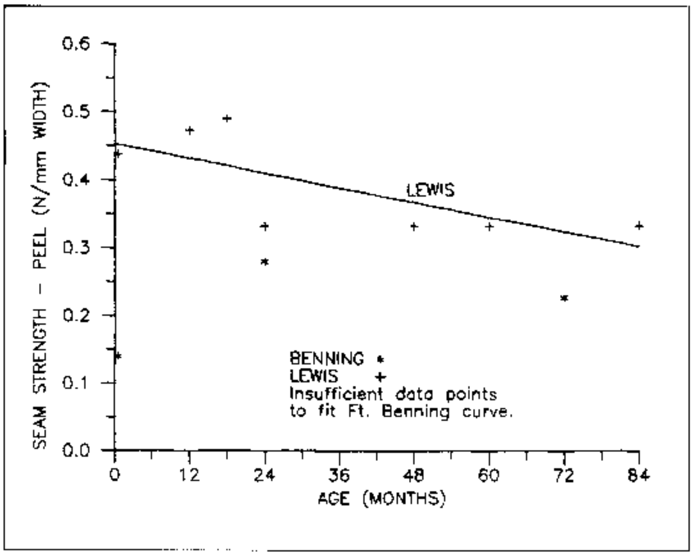

Figure 9 EPDM seam strength—peel.

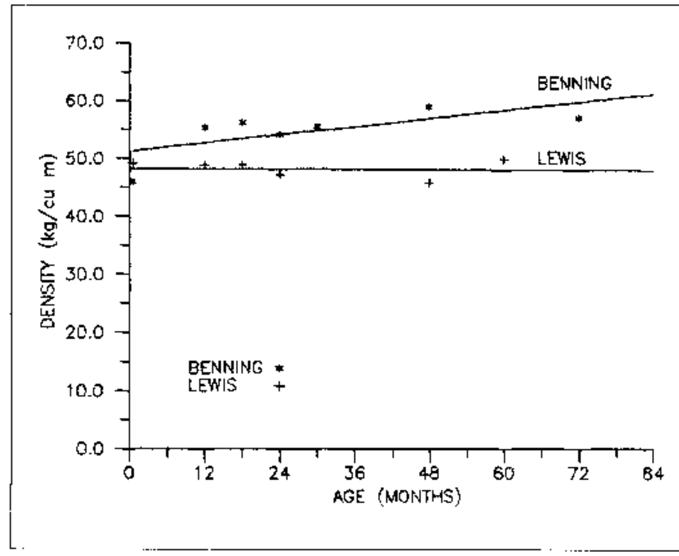

Figure 12 PUF density.

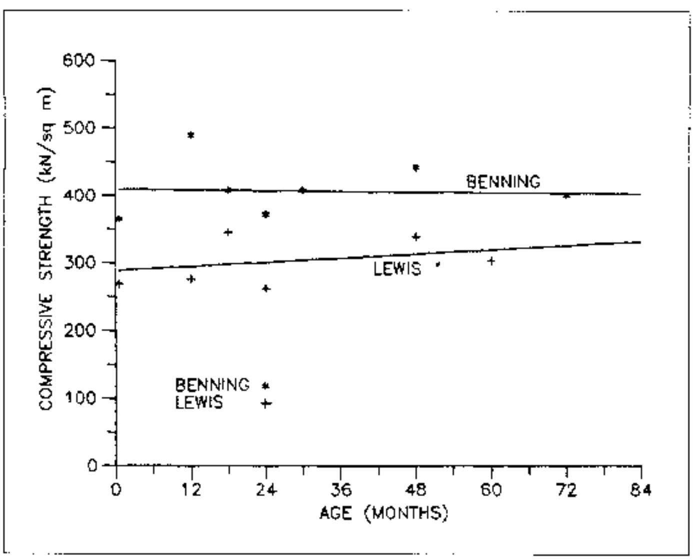

Figure 10 PUF compressive strength.

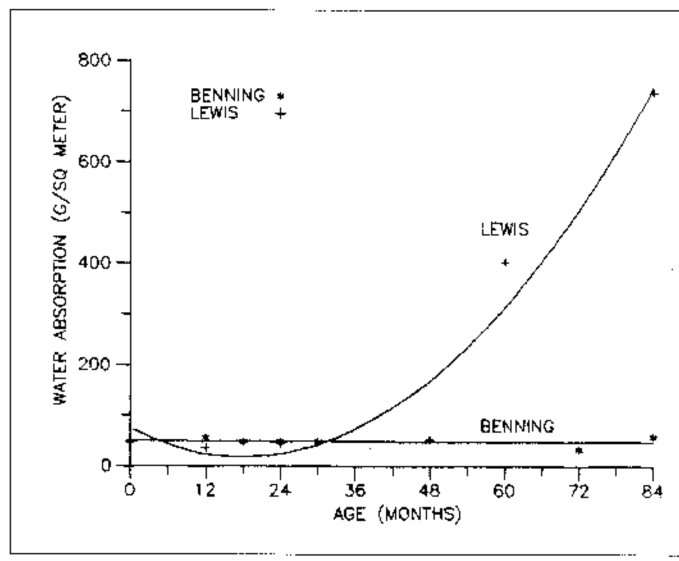

Figure 13 PUF water absorption.

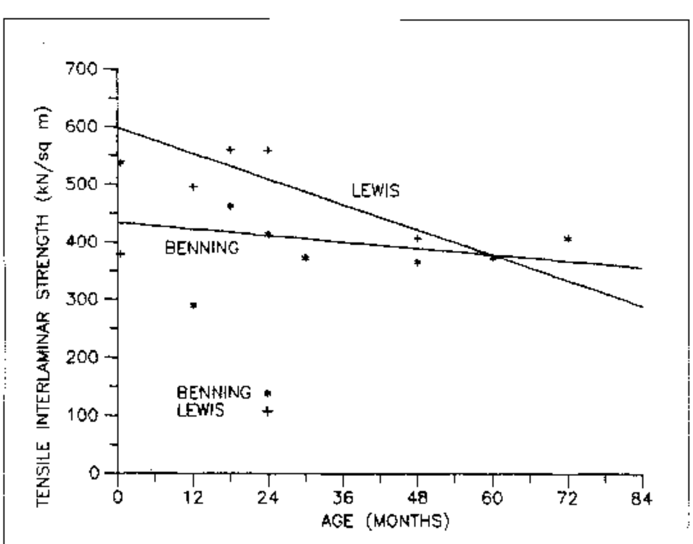

Figure 11 PUF tensile strength—interlaminar.

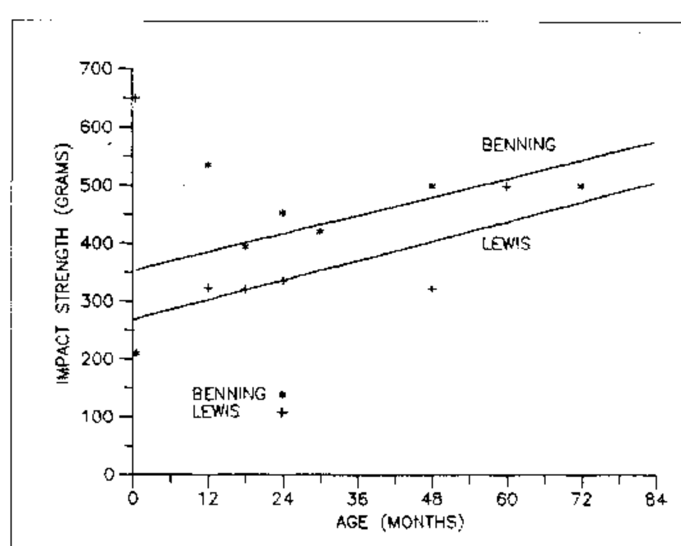

Figure 14 PUF impact strength.