SPRAYED-IN-PLACE POLYURETHANE FOAM ROOFING SYSTEMS, PROS AND CONS

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Introduction

Sprayed polyurethane foam (PUF) roofing systems have been successfully applied to virtually every type of roof deck and substrate in all climates. Their worldwide use includes areas subject to hail, over buildings housing coolers or freezers, over laundries (high humidity areas), and in tropical, subtropical, and desert areas with intense solar radiation and/or high humidity. Admittedly, application of PUF in such varied conditions has not been trouble free, a fact attested by many horror stories. Durable sprayed PUF roof systems can be achieved, however, through proper material selection, substrate preparation, and application.

Sprayed PUF roof systems, properly designed, applied, and maintained, with recoating after eight to 12 years, should provide at least 20-year service lives. They offer the following advantages:

- light weight
- relatively strong, high-quality insulation
- excellent adhesion to all types of roof decks
- complete filling and sealing as expanding PUF reaction is completed
- self-flashing
- adaptability for taper to slope
- adaptability to irregular roof surfaces
- easy maintenance and repair
- elimination of joints by its monolithic, seamless nature

The need for proper material selection, substrate preparation, and application has been demonstrated by extensive investigations performed by the Naval Civil Engineering Laboratory (NCEL). (Ref. 1 through 7) Other laboratoires have also conducted studies of these materials. (Ref. 8 through 11).

This paper accordingly present the pros and cons of specifying sprayed PUF roof systems. As noted above, poor PUF roof system performance can usually be attributed to improper materials or improper application. The following discussion analyzes the requirements for good foam materials and proper application procedures for these versatile roof systems.

The Learning Curve

Sprayed PUF roof systems were introduced some 15 to 20 years ago. As with most new materials, there were many misconceptions about the PUF, the protective coating systems, and their application parameters. These systems were promoted by some as a panacea for roofing problems. As a result, many ill-conceived, improperly specified and improperly applied jobs were sold to unsuspecting building owners. Equipment for foam application was relatively new, and sometimes undependable. The foam industry was in its infancy, near the bottom of the learning curve. Many early applicators neither understood nor appreciated the potential and versatility of these materials.

During the past 15 years, the industry has progressed far along the learning curve. Today's equipment, materials, and application techniques are far superior to their original counterparts. At least part of this progress can be attributed to the increasing influence of the Urethane Foam Contractors Association (UFCA). Following the lead of NRCA, UFCA has been publishing information directed toward educating the industry in the proper selection and application of foam and coating materials (Ref. 12).

Proper Selection and Application

Sprayed PUF roofs are not suitable for all reroofing jobs — notably roofs with continuous ponding water. Where foam appears to be the best choice for a specific project, a number of factors concerning materials selection and application procedures require close scrutiny, discussed in the following section.

Foam Requirements

A number of physical characteristics are required for sprayed PUF to perform to its optimum capability. These physical requirements, determined from field experience and research, are listed in Table 1.

When PUF was first marketed, a density of 2 pcf or less, with a compressive strength of 25 to 30 psi, was the industry standard. Experience has shown that a 2.5 to 3.5 pcf density foam, with a minimum compressive strength of 40 psi, produces better roof systems. Compressive strength is a more important factor than the density, because foam with a higher compressive strength is less subject to mechanical damage than foam of lower strength.

For optimum results, foam lifts should range between ½ in. and 1 in. thickness. If applied too thin, developing stresses can cause delamination. Too thick an application may impair the foam's physical properties. Minimum thickness for a good PUF roof should be no less than 1 in.; roofs thinner than 1 in. generally do not perform well. Foam should have definite terminations, without feathering.

Cell structure of the sprayed foam should be of a small and uniform size which is easily achieved. Irregularly shaped cells or cells of widely varying size may indicate spraying over a wet substrate. They may also indicate improper application techniques or poor materials. Moreover, the closed-cell content of the foam structure should be 90% min. by volume. Lower values result in reduced insulating value and inferior physical properties.

The surface texture of a sprayed foam roof has a significant effect on system performance. Surface textures are designated as smooth (most acceptable), orange peel, coarse orange peel, verge of popcorn, popcorn or treebark. The latter two are totally unacceptable. Photographic reference standards are shown in Figure 1.

Popcorn and treebark surfaces are not acceptable for two reasons: (1) the foam comprising the surface texture is generally of poor quality, and (2) the rough surfaces are almost impossible to coat without producing pinholes in the coating. Foam with unacceptable surface textures should be removed and the defective areas properly refoamed.

Coating Requirements

Because of its rapid degradation on exposure to sunlight, polyurethane foam must be protected by a suitable elastomeric coating (Ref. 1, 2, 5, 8-10, 12). The authors' experiences suggest that early failure of many PUF roof systems, though properly specified and applied, can be attributed to too thin a coating. As a result, NCEL currently recommends 30 mils as the minimum dry-film coating thickness. Some generic types of coating systems may require even greater dry-film thicknesses.

There are a number of high-quality coating systems that, when applied properly at the proper dry film thickness, will assure a long service life for PUF roofing systems. These include urethanes, silicones, acrylics, butyls, neoprenes, and hypalons.

These coatings may be subdivided further into permeable (breathing) and impermeable (non-breathing) coatings. (Where the potential for a strong moisture drive exists, such as buildings housing freezers or roofs with some ponding water problems, a high quality, well applied impermeable coating must be used.)

There is some question within the industry about the best coating material. Currently, the catalyzed or two-component urethanes, the silicones, and the acrylics are the most widely used materials for PUF roofs. All the coatings listed above have their own unique advantages. The coating system best suited for a particular roof should be selected.

When foam was first introduced as a roofing material, a wide variety of coating systems were used to protect the foam. These include house paints, asphaltic materials, and cementitious types. Experience has shown that many of these materials fail very rapidly (often within 6 months) because they lack the required flexibility.

Although the importance of foam surface texture has already been discussed, it is particularly important for the coating phase of the roof construction. Rough surface textures obviously have more actual surface area than smoother surfaces and consequently require more coating to achieve the required 30 mils minimum dry-film thickness. A coating that provides a 30 mil dry-film thickness on a smooth surface at an application rate of 3 gallons per square may require over 4 gallons per square when applied to a verge of popcorn surface. If surface texture is not considered, the consequently deficient coating thickness will lead to premature coating failure.

After the foam has been applied, there is a limiting time during which the basecoat must be applied. When the basecoats are applied too quickly after foaming, coating solvents can affect the PUF's surface integrity, or foam offgassing can cause the coating to pinhole. If too long a period passes between foaming and coating, and the foam surface is degraded by sunlight, the coating may not adhere to the foam. No more foam should be applied on a given day than can be reasonably basecoated the same day. If unanticipated delays do occur, the elastomeric coating should be applied no later than 72 hours after foaming. Foam should cure a minimum of 2 hours before applying the basecoat.

Mineral roofing granules are frequently sprinkled into the wet topcoat of silicone and acrylic elastomer coatings at the rate of 50 pounds per square. The granules will improve the following surface properties:

- abrasion resistance
- resistance to bird pecking
- weathering characteristics
- fire resistance
- aesthetics

Properly sprayed granules should thus extend the useful life of a PUF roof system.

The Total Roof System

Information provided so far has dealt primarily with individual components of the sprayed PUF roof system. However, it is the total system, PUF and coating, that determines its performance. NCEL has been pursuing research to establish performance criteria for sprayed PUF roof systems (Ref. 1 and 2). Important properties — e.g., coating adhesion to the foam, impact resistance, moisture resistance, and the coating tensil properties — are monitored as the systems age. When tests are completed, an attempt will be made to correlate the results with the systems performance and, if possible, establish performance criteria for specifying new systems.

In an era of escalating energy costs, one of the most important characteristics of a PUF roof is its excellent insulating properties. The excellent insulating efficiency of PUF can be attributed to the capture of the fluorocarbon blowing agent in the closed cells during the formation of the rigid foam. This provides an initial thermal conductivity (k-value) of 0.11 to 0.14 BTU/hr-ft^2-°F/in., the lowest k-value for any of the common insulating materials. However, concern has been expressed that the thermal conductivity will decay as the PUF roof system ages and the fluorocarbon gas migrates from the cells and is replaced by air. NCEL has investigated this aspect of sprayed roof systems by collecting over 60 samples of weathered PUF roofs from five different geographical areas in the U.S. and Pacific areas. These samples, which varied in age from 1¼ to 1½ years, were returned to the Laboratory and their thermal conductivity determined. Results are summarized in Table 2 (Ref. 6). These data generally validate the value given for aged PUF in the ASHRAE Handbook (Ref. 13) k = 0.16 BTU/hr-ft^2-°F/in. Even when the k-values increases above 0.16 BTU/hr-ft^2-°F/in., it is still equal to or better than the next best insulating material, extruded styrofoam.

One aspect of PUF roof systems that has gained much notoriety is their fire safety properties. Foam roofing material will burn like any other organic roofing material. Most building codes consequently require a Class II foam, or better, i.e., a flame spread of 75 or less when tested in accordance with ASTM E-84 or Underwriters Laboratories (UL) 723. A more important consideration is the fire safety characteristics of the total sprayed foam system as determined by UL or Factory Mutual (FM) testing. The authors contend that sprayed PUF roof systems should meet the same UL or FM fire safety criteria as conventional roofing, i.e., FM Class I, or UL 790 for top of the roof fires and UL Subject 1256 (Roof Deck Construction Classification-RDC) for fires originating within a building.

There are numerous foam roof systems with a UL 790 classification. However, there has been concern about applying foam directly to metal decks because of potential propagation of fire within the building by the off-gassing foam as it burns. NCEL has conducted a great deal of fire testing of foam roof systems applied directly to metal decks at Underwriters Laboratories. These tests have been most successful. (Results of tests over Butlerib metal decks are given in Reference 3.) Results have shown that the fire safety of PUF roof systems applied over metal decks is comparable, if not better than, fire acceptable insulated built-up roof systems on metal decks. One additional advantage of foam in such a fire is that it does not melt and drip into the fire. Foam merely decomposes in place as it burns.

The NCEL tests at UL have resulted in more than 35 PUF systems classified under RDC No. 136 for use over Butlerib metal decks, and 10 systems under RDC No. 181 for use over corrugated metal. Additional systems are now being classified for direct application over fluted metal decks.

Roof Decks

As previously noted, PUF roof systems have been used successfully over virtually every type of roof deck, including wood, concrete and metal decks, and over existing dry built-up roofs. Each has its own peculiar requirements for a satisfactory job.

As the most basic rule for a satisfactory substrate: **PUF should not be applied directly over a wet BUR.** Such an application will lead to early failure.

PUF systems have been used successfully over roof deck slopes from vertical to dead level. They are particularly useful on roof decks that have special configurations and in some cases may be the only system that can satisfactorily waterproof such roofs. Although PUF has been used successfully on flat roofs, there have also been many problems. In many cases, these problems can be attributed to improper materials, improper application or application over a wet conventional roof system. However, application to dead level roofs or roofs with serious ponding water problems leaves little margin for error regardless of the type of roof system. A minimum slope of at least 1/4 inch per foot is always recommended. Where ponding water may be a problem, a high quality impermeable coating rather than a permeable coating should be used.

Vapor retarders may also be required for PUF roofs. A good rule of thumb is to use a vapor retarder under a PUF roof if it appears to be required for a conventional roof system.

Application

There is no substitute for the proper application of a PUF roof system. Proper application is easily accomplished by an experienced foam mechanic. There are a few cardinal rules, discussed below.

All necessary repairs to the existing roof or roof deck should be made prior to applying primer or foam. Priming may or may not be required depending on the job circumstances. Although foam has excellent adhesion to most substrates, wood or concrete may require priming for waterproofing, metal may require an anticorrosive primer, and a BUR membrane may be primed to incapsulate any residual material not removed during the cleaning operation. When primers are required, they should be those recommended by the foam manufacturer.

Prior to priming or foaming, the roof deck or substrate should be properly cleaned of all dirt, dust, oil, grease, ice, frost, or other contaminants. One of the most fundamental requisites in the successful application of sprayed urethane foam is that the foam be applied only to a dry surface. The rule is absolute, because freshly sprayed foam reacts very vigorously with liquid moisture.

During the foaming operation, all applicators should wear rubber-soled, flat, heelless shoes to prevent damage to the foam prior to reaching its optimum properties. Also while foaming, improperly metered or other poor quality materials should not be sprayed on the roof when adjusting equipment. Such materials should be sprayed into disposable containers and removed from the roof. If equipment malfunction occurs during the spray operation, resulting in an improperly proportioned mixture, the poor quality foam must be removed and the area refoamed.

Probably the greatest disadvantage of the PUF system is its high dependence on weather conditions. PUF should not be applied under the following conditions:

- when rain is imminent
- when roof surface is above 120°F or below 50°F
- when wind speed exceeds 12 mph (unless windscreens shield the spraying area)
- when wind speed exceeds 25 mph (with windscreens)
- when substrate temperature is within 5°F of dewpoint temperature

Observance of the above rules is required to keep the chemical reaction unaffected by moisture, by retardation at low temperature or acceleration at high temperature. Thus the limitations on ambient temperature and application during precipitation. Excessive wind speed can ruin surface texture and cause overspray. Moisture and overspray are the most common causes of interlaminar blistering.

Inflating an airbag over the roof, to promote a controlled, isolated environment is another way to avoid weather-caused problems.

Because of the sensitivity of freshly applied foam to liquid moisture, some believe that foam cannot be satisfactorily applied in a humid environment, such as the southeastern part of the United States or in tropical areas. The authors disagree; they have seen many fine PUF roofs in humid areas. The key to humid-climate PUF construction is the last rule listed above: assuring that dew-point temperature is at least 5 °F above substrate temperature during application. Otherwise, moisture on the surface being sprayed will impair foam quality.

Summary

Information has been presented detailing many of the procedures and requirements necessary to obtain a good, durable foam roof. Sprayed foam roofs, when properly specified, properly applied and provided with a low-level maintenance should last 8 to 12 years before recoating is necessary. With a minimal annual maintenance, and recoating at the proper cycle, a good foam roof should provide at least a 20-year life. The vast majority of the recommended practices given above are not difficult to institute. Following these practices along with careful selection and specification of materials appropriate for a job, PUF roofs will provide outstanding service.

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Density (Sprayed-in-place)	D 1622	pcf	2.50-3.50
"k" factor (aged)	C 177 or C 518	Btu per sq ft, hr, degree F per inch	0.16 (max)
Compressive Strength Parallel to Foam Rise	D 1621	psi	40 (min)
Shear Strength	C 273	psi	35 (min)
Dimensional Stability (humid aging) 28 days 160°F, 100% Relative Humidity	D 2126 Procedure F	percent net volume change	15 (max)
Water Vapor Permeability	C 355	perm-in	3.0 (max)
Percentage Closed/Open Cells	D 1940, D 2856	percent by volume	90 (min), 10 (max)
Water Absorption (96 hours under 2 in head)	D 2842	psf	0.10(Max)

TABLE 1. Required Physical Properties for Cured, Sprayed-in-Place PUF

Location	Permeable Coatings Average		Number of Samples		Imperm. Coatings Average		Overall Average		No. of Samples
	k-Value	Age (yrs)	Perm.	Imperm.	k-Value	Age (yrs)	k-Value	Age (yrs)	
CLIFTON, N.J.	0.170±0.010	5.0	8	8	0.146±0.008	5.0	0.158±0.015	5.0	16
DENVER, CO	0.191±0.012	7.1±2.9	5	2	0.180±0.016	10.1±0.5	0.188±0.013	8.0±2.8	7
SUBIC BAY, R.P.	0.175±0.013	5.2±1.0	6	—	—	—	0.175±0.013	5.2±1.09	6
GUAM, M.I.	0.195	5	1	—	—	—	0.191±0.005	8.3±2.9	3
PORT HUENEME, CA	0.153±0.624	5.0±2.4	17	11	0.156±0.017	6.6±0.9	0.154±0.021	5.7±2.1	28
TOTAL	0.164±0.023	5.8±3.4	37	21	0.156±0.017	7.3±3.0	0.163±0.022	5.8±2.1	60

TABLE 2. Average k-Values and Ages of Weathered PUF. (k = BTU/hr-ft^2-°F/in.)

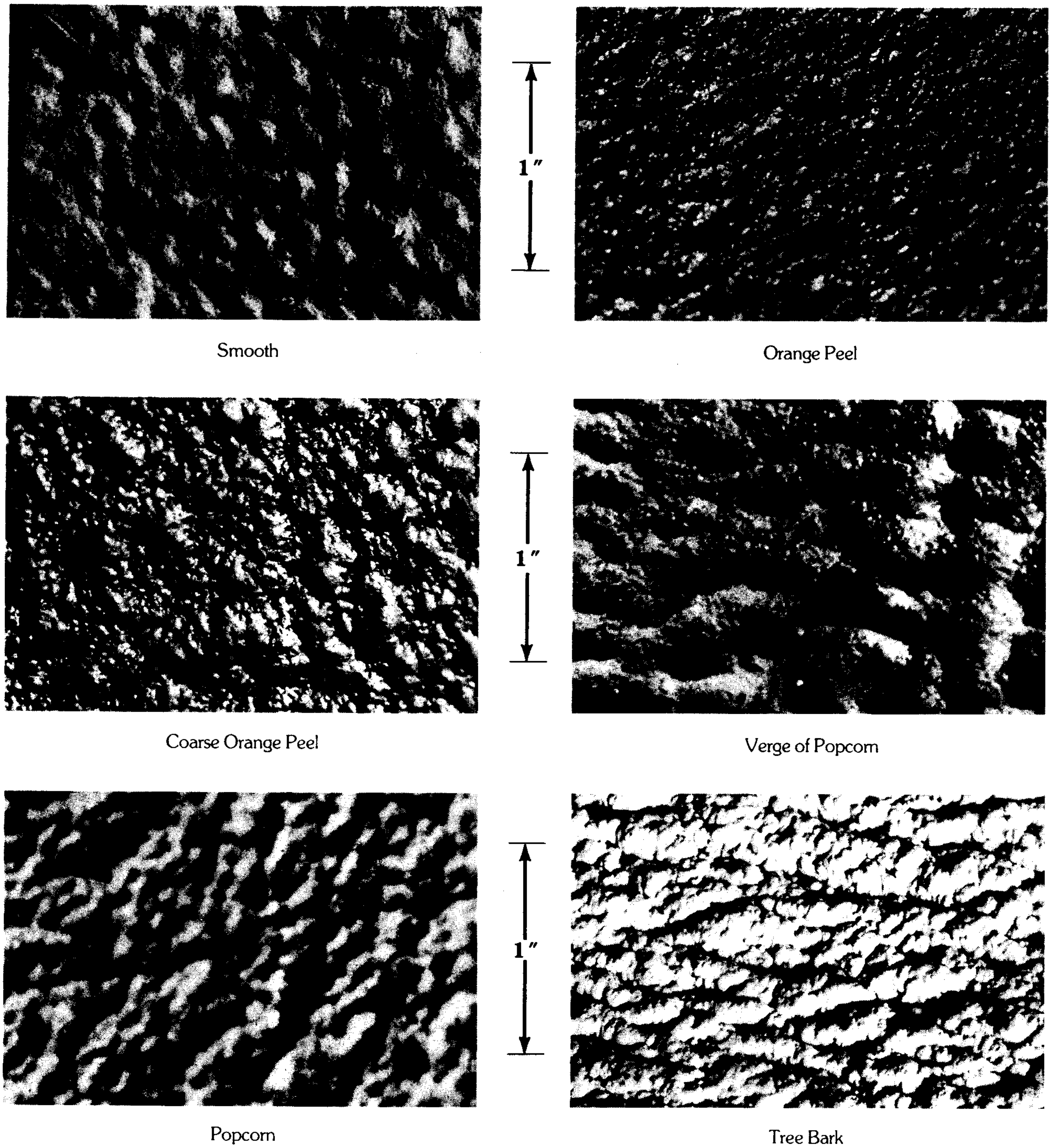

FIGURE 1. Surface Texture Standards for Spray-Applied Polyurethane Foam.